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AUTOMATED WEAPON SYSTEM TRAINER: EXPANDED ADAPTIVE MODULE FOR B--ETC(U)

AUG 77 J P CHARLES, R M JOHNSON N61339-74-C-0141

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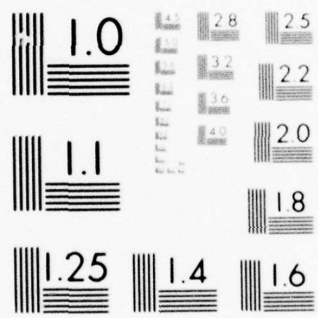

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AUTOMATED WEAPON SYSTEM TRAINER: EXPANDED ADAPTIVE MODULE FOR BASIC INSTRUMENT FLIGHT INSTRUCTION

Appli-Mation, Inc.
Orlando, FL 32803

Final Report for period June 1974 - July 1976

August 1977

DoD Distribution Statement

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NAVAL TRAINING EQUIPMENT CENTER
ORLANDO FLORIDA 32813

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NAVTRAEQUIPCEN 74-C-0141-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Automated Weapon System Trainer: Expanded Module for Basic Instrument Flight Maneuvers		5. TYPE OF REPORT & PERIOD COVERED Final Report June 1974 - July 1976
		6. PERFORMING ORG. REPORT NUMBER AISR/376
7. AUTHOR(s) Dr. John P. Charles Mr. Robert M. Johnson		8. CONTRACT OR GRANT NUMBER(s) NAVTRAEQUIPCEN N61339-74-C-0141
9. PERFORMING ORGANIZATION NAME AND ADDRESS Appli-Mation, Inc. 11772 Sorrento Valley Rd., Suite 101 San Diego, CA 92121		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NAVTRAEQUIPCEN TASK NO. 2753-03P01
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Training Equipment Center Orlando, FL 32803		12. REPORT DATE August 1977
		13. NUMBER OF PAGES 200
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

18 6 9 19 14 10 15 11 12 200p. Adaptive new

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Automated Training
Adaptive Training
Instrument Maneuvers Training
Simulator Training

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Previous studies have demonstrated the conceptual and technical feasibility of automated and adaptive aviation simulator training. This study was concerned with exploring the impact of operational syllabi and training requirements on these advanced techniques. The Advanced Jet Instrument Training syllabus was selected and analyzed. A demonstration of the application of automated and adaptive techniques to the syllabus was conducted utilizing the

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20. Abstract (cont.)

R&D simulator at the Naval Training Equipment Center. Several new approaches to performance measurement, syllabus structuring and training control were developed to meet the syllabus requirement and training objectives. The techniques and applications were successfully demonstrated.

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SUMMARY

While the technical feasibility of utilizing automated and adaptive training techniques for ground based aviation pilot training has been demonstrated, the actual applications to operational training objectives have not been investigated. This study was directed to the analysis of the mutual impact of current basic instrument flight syllabi in use at Naval pilot training squadrons and the advanced training techniques. The Advanced Jet Training Syllabus was selected for analysis and demonstration utilizing the TRADEC R&D simulator at the Naval Training Equipment Center.

The analysis of the syllabus resulted in the need for several new modules and methods for implementing automated-adaptive training. These included:

- Task segmentation - for automated control and objective performance measurement.

- Three types of performance measures -

  (1) Procedures measures which sample task knowledge or cognitive performance.

  (2) Control measures which sample psycho-motor performance.

  (3) Task measures which sample operational performance.

- Sub-syllabus development - for training on specific sub-tasks.

A representative set of the precision and confidence maneuvers analyzed was selected for demonstrations and implemented on the TRADEC simulator.

Air-to-air attack (stern conversions) were also analyzed and implemented using the same techniques.

The demonstrations were successful and it was concluded that the approach should be evaluated on an operational training simulator such as Device 2F90. It was recommended that the potential for improved syllabus control utilizing the new approaches to performance measurement, sub-syllabus branching, and task segmentation be explored.

Finally, the importance of properly designing the instructor interface to manage a training system with the advanced techniques was stressed.

PREFACE

The authors wish to acknowledge the assistance and cooperation of the Navy personnel who assisted in the analysis and review of instrument training syllabi. In particular, the efforts of Instructor personnel of the following squadrons is appreciated.

Jet Training

Training Squadron Twenty-Four (Basic)
NAS Chase Field, TX

Training Squadron Twenty-Six (Advanced)
NAS Chase Field, TX

Readiness Training

Fighter Squadron One-Twenty-Six (Instruments)
NAS Miramar, CA

Fighter Squadron One-Twenty-Four (F-14A)
NAS Miramar, CA

Fighter Squadron One-Twenty-One (F-4J)
NAS Miramar, CA

Mr. Steve Barnaby of Canyon Research Group Inc., assisted in the modeling of the air-to-air attack simulation and contributed significantly to the analysis and the critique of the implementation of the model.

Finally, particular appreciation is expressed to the project Scientific Officer, Mr. Ira Goldstein, who provided insight into problem areas and coordinated efforts of the program.

FOREWORD

Since 1969, the Human Factors Laboratory of the Naval Training Equipment Center has sponsored the development of an automated and adaptive flight simulator training system, and the present report is one of a series that documents the automation of flying situations for that system. To date, the system can provide training on basic confidence maneuvers, GCA and ILS approaches, and air-to-air attacks; and two evaluations of these developments have taken place - one at the undergraduate pilot level and one at the advanced level. The present work has extended the capabilities of the program's basic instrument maneuvers section by incorporating recent developments in performance measurement, syllabus structure, and adaptive logic - all in the context of the Advanced Jet Syllabus.

Our next effort will be to assess this development using the TRADEC research and development simulator, with the results of that work guiding the adaptation of the system for an operational flight trainer.

Ira Goldstein

IRA GOLDSTEIN
Scientific Officer

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SECTION I

INTRODUCTION

BACKGROUND

Beginning in 1971, the Naval Training Equipment Center undertook a sequence of studies to demonstrate the conceptual and technical possibility of exploiting advanced training methodology and simulation technology, especially computer related technology. Three initial studies involving simulation training were undertaken. The first was directed to a general flight task - the Ground Controlled Approach.[1] The second was directed to a student training task - basic flight maneuvers.[2] The third was directed to an operational training task - air-to-air missile attack.[3] The studies were successful and demonstrated that:

a. The state-of-the-art of computer software and hardware technology was not constraining the application of advanced simulation training techniques.

b. Automated simulation training was possible including the basic training functions of:

(1) Simulator initialization.
(2) Training session monitor and control.
(3) Objective performance measurement.

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[1] Charles, John P. and Johnson, Robert M. Automated Training Evaluation (ATE). Technical Report NAVTRADEVCEN 70-C-0132-1, Naval Training Device Center, Orlando, Florida. January 1972.
[2] Charles, J. P., Johnson, Robert M., and Swink, Jay R. Automated Flight Training (AFT) Instrument Flight Maneuvers. Technical Report NAVTRAEQUIPCEN 71-C-0205-1, Naval Training Equipment Center, Orlando, Florida, February 1973.
[3] Charles, John P., Johnson, Robert M., and Swink, Jay R. Automated Flight Training (AFT) GCI/CIC Air Attack. Technical Report NAVTRAEQUIPCEN 72-C-0108-1, Naval Training Equipment Center, Orlando, Florida, 1973.

(4) Adaptive syllabus structuring.

(5) Human air controller modeling and simulation.

(6) Aircrew modeling and simulation.

(7) Basic instructor function modeling and simulation.

(8) Training management including syllabus control and student records.

c. Automated-adaptive training appeared acceptable to pilots.

d. Potentially significant savings in training time could be achieved through adaptive training.

e. Considerable unburdening of the instructor could be achieved with attendant saving in instructor personnel and training requirements.

In short, the studies opened a wide area of potential enhancements to simulator training. The studies also highlighted the lack of required research data in certain areas such as performance measurement and evaluation, instructor functional objectives and adaptive training algorithms.

EARLY STUDY LIMITATIONS

The early laboratory studies of automated-adaptive training techniques were directed to exploring the concept, resolving risk development areas, developing usefulness data and demonstrating the technical and implementation feasibility. They addressed primarily the areas of objective performance measurement, adaptive scheduling, automated training and the modeling and simulation of human controller and instructor functions. Being Research and Development (R&D) studies, only those training system components required for the demonstration were developed. Therefore, the studies did not involve the development of a complete or

operational training system.

In particular, the following components or training subsystems were not developed beyond minimum functional or interface requirements.

- training syllabi
- performance criteria
- student training files
- learning objectives
- student briefing/debriefing

In addition, the use of a laboratory general purpose research and development simulator precluded specific weapon system application and training evaluation since:

- only a generic simulator was used
- few students were available
- no instructors were available

The syllabus utilized in the GCA study, for example, was designed to explore the automated adaptive mechanization, not to train student aviators in GCA approaches. The "instructor interface" used included only the displays and controls necessary to initiate and monitor the "breadboard" automated adaptive system.

The performance measures developed for the R&D studies were relatively simplistic measures designed to permit adaptive scheduling within the syllabus which itself was generic in nature. The adaptive algorithms were designed to demonstrate the feasibility of on-line syllabus restructuring and the stability of such restructuring. The adaptive variables or difficulty factors utilized reflected the simulator capabilities and generic nature of the syllabus.

In short, the R&D system was designed to "exercise" the advanced developments to achieve the required demonstration.

FIELD DEMONSTRATIONS

The operational acceptability and the usefulness of the advanced training concepts were explored in two studies, one by the U. S. Navy and one by the U. S. Air Force.

Both utilized the GCA task for the evaluation. In the report of the Navy evaluations at NAS Chase Field utilizing training Device 2F90 (TA-4J Operational Flight Trainer), Puig[4] concluded that the usefulness and feasibility were established. In the report of the U. S. Air Force evaluation involving an F-4E Weapons System Trainer at Luke Air Force Base, Brown[5] concluded that the techniques provided an "effective system for training GCA's." Both studies pointed out some shortcomings in the system implemented, especially the limited nature of the task utilized, the need for more data on the training features involved and requirements for improved syllabi and adaptive variables.

SUMMARY

The R&D studies and field demonstrations of the concepts of automated and adaptive training have proven conceptual and technical feasibility as well as general acceptability and usefulness. The shortcomings of the "systems" to date reflect the demonstration nature of the developments rather than any basic problems or limitations in the concept.

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[4]Puig, Joseph A. and Gill, Susan, Evaluation of an Automated Flight Training System, in 8th NTEC/Industry Conference Proceedings 18-20 November 1975, Naval Training Equipment Center, Orlando, FL, pp. 77-88.
[5]Brown, James E., Waag, Wayne L. and Eddowes, Edward E., USAF Evaluation of an Automated Adaptive Flight Training System, Ibid., pp. 89-99.

SECTION II
PROBLEM

GENERAL

As reviewed in the Introduction, the sequence of early studies which successfully demonstrated the automated and adaptive training technology utilized very limited training tasks and a simplified training system. The impact and the requirements of a comprehensive operational training syllabus on the automated-adaptive approach remains to be determined before specifications for implementation on future WST's can be prepared. Therefore, the purpose of the study was to explore the mutual impact of current basic instrument flight syllabi in use at training squadrons and automated-adaptive instruction technology. The study was also extended to include air-to-air attack training.

OBJECTIVES

The objectives of the study were to analyze the current instrument training syllabi for fixed wing high performance aircraft and the role of the simulator in support of the syllabus and to develop and demonstrate the application of automated-adaptive technology to the syllabus using the TRADEC facility at the Naval Training Equipment Center. It was recognized that the demonstration would involve a subset of the overall syllabus compatible with the TRADEC. The expanded air-to-air attack syllabus was also demonstrated.

SECTION III

METHOD

GENERAL

A general systems engineering approach was utilized. Five basic tasks were identified and undertaken. The five tasks were:

(1) Task A. Syllabus Analysis and Definition.
(2) Task B. Training Design.
(3) Task C. Implementation.
(4) Task D. Demonstration.
(5) Task E. Documentation.

The five tasks were constructed to capitalize on the results of the earlier studies, especially in terms of software developments.

TASKS

Several sub-tasks were undertaken for each major task. They are briefly reviewed below:

TASK A. ANALYSIS SUB-TASKS. Sub-task one was concerned with identifying and analyzing basic instrument training syllabi and the demonstration constraint data.

The instrument training syllabi reviewed and analyzed reflected three different levels of training, namely pilot training syllabi, replacement instrument training syllabi, and readiness training syllabi. The pilot training syllabi included the basic jet training syllabus (T-2 aircraft and Device 2F-101 OFT syllabus) and the advanced jet training syllabus (TA-4J aircraft and Device 2F90 syllabus). The replacement instrument training syllabus (TA-4J aircraft) provides the basic instrument training for replacement pilots before beginning transition training. Two readiness training syllabi (F-4J/Device 2F88 and F-14A/

Device 2F95 syllabi) were reviewed. Instrument training at the Readiness Squadron level was considered to be the last formal instrument training provided pilots.

The advanced jet syllabus and the replacement instrument training syllabus were analyzed in detail since they contain the most demanding requirements in the pilot training program and in the replacement or readiness training program. Furthermore, the same aircraft is involved (TA-4J). Thus, both the training objectives and the criteria could be directly compared.

The demonstration constraint data analysis was concerned with the implementation and demonstration capability of the TRADEC system. The TRADEC includes a motion platform, and a general cockpit with only basic flight controls and instruments. No radio navigation aids are available.

Sub-tasks two and three of the definition and analysis task involved the development of the detailed training course requirements and the identification of the sub-set which could be implemented and demonstrated on the TRADEC system.

TASK B. DESIGN SUB-TASKS. The second major task involved the design efforts. Two separate sub-tasks were undertaken. The first was concerned with the design of the syllabus; the second with the design of the software.

TASK C. IMPLEMENTATION SUB-TASKS. Two sub-tasks were utilized to implement the design. The first involved the development of the computer program. The second achieved the integration and checkout of the system including the special cockpit and instructor station displays.

TASK D. DEMONSTRATION SUB-TASKS. Two sub-tasks were undertaken for the demonstration tasks. The first involved test of the system to the design criteria; the second involved the demonstration of the training system with a "student" in the cockpit. It included exercising the capabilities of the design.

TASK E. DOCUMENTATION SUB-TASKS. The final task involved documentation and preparation of the final technical report.

SECTION IV
RESULTS

ORGANIZATION

The results are presented in terms of the major analysis and design efforts conducted; specifically they are:

a. Syllabi Analysis
b. Instrument Flight Maneuvers Training Requirements
c. Demonstration Constraints
d. Function Analysis
e. Demonstration Design

- Syllabus Design
- Performance Measurement Design
- Adaptive Schedule Design
- Feedback Design
- Student Display
- Instructor Terminal
- Instructor Model
- Student Records
- Otner Sub-systems
- Air-To-Air Attack Design

f. Demonstration

SYLLABI ANALYSIS

Five training syllabi were reviewed in detail. The five are the syllabi utilized in the Navy high performance jet pilot training program from Basic Jet Training through Replacement Training. The five syllabi reviewed were:

(1) Basic Training (Jet), T-2A/B/C - Naval Air Training Command.

(2) Advanced Training (Jet), TA-4J - Naval Air

Training Command.

(3) Replacement Instrument Flight Training - VF-126 NAS Miramar.

(4) Replacement Pilot Training (F-4J) - VF 121 NAS Miramar.

(5) Replacement Pilot Training (F-14A) - VF-124 NAS Miramar.

The flight maneuvers identified in the syllabi were grouped under four categories:

(1) Basic Flight Maneuvers
(2) Precision Flight Maneuvers
(3) Confidence Flight Maneuvers
(4) Other

While somewhat arbitrary, the categories are commonly used throughout the Navy and also by the Air Force, Army and general aviation. They reflect a generally increasing skill requirement, i.e., proficiency in basic flight maneuvers is required for precision and confidence maneuvers and training in precision maneuvers typically precedes confidence maneuvers.

U. S. Air Force syllabi for T-37, F-4E, F-111, and A-7D training were also reviewed. In general, the instrument maneuvers training parallels that utilized by the Navy.

The maneuvers analyzed in each category are listed in Table 1. It also identifies the syllabi or phase of training in which the maneuver is utilized.

TABLE 1. MANEUVERS BY STAGE OF TRAINING

MANEUVER	BASIC JET	ADVANCED JET	RTS INSTRUMENTS	READINESS SYLLABUS
BASIC				
Straight & Level	x		x	
Basic Transitions	x	x	x	
Climbs & Dives Constant Speed	x		x	
Climbs & Dives Constant Speed/Rate	x			
Constant Angle Banks	x	x		
Standard Rate Turns	x	x		
Climbing Diving Turns	x			
PRECISION				
Turn Pattern	x	x	x	
Vertical S-1	x	x	x	
S-2		x	x	
S-3	x	x		
Yoke 1	x			
CONFIDENCE				
Aileron Roll	x	x	x	x
Wingover	x	x	x	x
Barrel Roll	x	x	x	x
Loop	x	x		x
Half Cuban Eight	x	x	x	x
Immelmann	x	x	x	x
Split-S		x	x	
Squirrel Cage		x		

TABLE 1. MANEUVERS BY STAGE OF TRAINING (cont.)

MANEUVER	BASIC JET	ADVANCED JET	RTS INSTRUMENTS	READINESS SYLLABUS
OTHER				
Approach to Stall	x	x	x	x
Unusual Attitudes	x	x	x	x
Standard Instrument Departure	x	x	x	x
Penetration	x	x	x	x

The table shows the general progression and concentration on more complex maneuvers as training progresses. However, what is not obvious is that simpler skills or maneuvers are practiced at all levels since the more complex maneuvers are combinations and sequences of the simpler tasks. This holds true even at simple levels. For example, basic transitions which are speed changes, require the ability to maintain straight and level flight. Furthermore, while basic maneuvers are not utilized as such at the readiness training squadron level, related but less structured training missions are scheduled to explore the aircraft's handling characteristics. However, they are not identified as specific flight maneuvers nor do specific performance criteria exist.

Basic Jet Training instrument maneuvers consist primarily of the following instrument flight tasks:

a. Straight and level flight
b. Basic transitions (speed and altitude)
c. Constant rate/airspeed climb and descents
d. Constant angle of bank turns
e. Standard rate turns
f. Climbing/diving turns

Precision and confidence maneuvers are also introduced. These maneuvers integrate the basic skills acquired during practice of the flight tasks identified above. The maneuvers include:

a. Turn pattern
b. "S-1" pattern
c. "S-3" pattern
d. Yoke Pattern
e. Aileron roll
f. Wingover
g. Barrel roll
h. Loop
i. Half Cuban Eight
j. Immelmann

In addition, approaches to stall and unusual attitude recovery are demonstrated.

Advanced jet instrument maneuvers includes practice of the precision maneuvers and confidence maneuvers, as well as additional airways training (e.g., penetrations). The confidence maneuvers, while representing further integration of basic skills, are considered more a familiarization exercise than an acquisition of specific skills. Thus, the performance criteria for confidence maneuvers are relatively broad. The advanced jet instrument maneuvers include the following:

a. "S-1" pattern
b. "S-2" pattern
c. "S-3" pattern
d. Aileron roll
e. Wingover
f. Barrel roll
g. Loop
h. Half Cuban Eight
i. Immelmann
j. Split-S
k. Squirrel cage
l. Penetrations

Ground controlled approaches are introduced in basic jet and practiced in advanced jet.

The different emphasis of basic and advanced jet is reflected in the syllabus organization. The stages in each syllabus are listed below. They are arranged to highlight the similarities. The arrangement does not reflect acutal sequence

of training. As can be seen, where basic jet concentrates on flight skills, advanced jet builds on these skills with more of an operational orientation.

Basic Jet	Advanced Jet
Familiarization (FAM)	Familiarization (FAM)
Basic Instruments (BI)	Basic Instruments (BI)
Radio Instruments (RI)	Radio Instruments (RI)
Formation (F)	Formation (F)
Night Familiarization (NF)	Night Familiarization (NF)
Gunnery (GUN)	Weapon (WEP)
Carrier Qualification (CQ)	Carrier Qualification (CQ)
	Airways Navigation (AN)
	Tactical Formation (TACF)
	Operational Navigation (ON)
	Air Combat Maneuvering (ACM)

The operational phase of training represented by transition or readiness training extends further the emphasis on operational flying skills and the integration of the basic flight and elementary operational skills developed in basic and advanced jet training. The F-4J syllabus, for example, consists of four stages.

(1) Familiarization
(2) Radar Weapons
(3) Data Link
(4) Electronic Warfare

A review of instrument flight requirements is conducted in TA-4 aircraft. The emphasis is on TACAN navigation, penetrations, and approaches. The syllabus assumes the student is capable of flying all precision and confidence maneuvers and has the basic skills for operational transition. Precision maneuvers are utilized for proficiency demonstration and confidence maneuvers

for aircraft familiarization. Performance criteria reflect only airways or operational requirements rather than any part-task or specific maneuver excellence. Demonstration of basic knowledge and flight skills in terms of safe flight is the essential requirement.

Thus, the overall instrument maneuvers training program can be summarized as a sequential program. Basic skills are taught to strict criteria, then integrated into precision maneuvers. Confidence maneuvers are then introduced and practiced to a relatively high skill level. Once each skill is acquired, performance requirements are altered to reflect operational criteria. Thus, the same degree of precision required for a TACAN penetration in the advanced jet syllabus is not a requirement in later transition training.

INSTRUMENT FLIGHT MANEUVERS TRAINING REQUIREMENTS

The advanced jet syllabus was selected for detailed analysis and design since, (1) the maneuvers and criteria are well defined, (2) the syllabus includes all levels of maneuvers, and (3) the syllabus includes extensive support from a training simulator. Fifteen flight maneuvers were analyzed in detail in terms of:

(1) Definition or Description
(2) Basic Supporting Maneuvers
(3) Detailed Procedures
(4) Performance Criteria
(5) Potential Difficulty Factors

The fifteen included Precision, Confidence and "other" maneuvers. The basic maneuvers such as straight and level flight do not form a part of the syllabus at the advanced jet level. Appendix A contains the results of this analysis. It forms the basis for the automated-adaptive syllabus design.

The goal was to identify quantitatively, the characteristics of the maneuvers and the flight procedures required to perform them. These data were essential for the segmentation of maneuvers for automated control, for individualized or adaptive control, and for student difficulty diagnosis.

The analysis concentrated on identifying relevant parameters for each maneuver, their condition (steady state or dynamic) within each segment, and their sequence throughout the maneuver. For example, in the loop, bank and yaw angles are held constant - deviations represent performance "errors". The first portion of the loop is flown at constant acceleration (G), until Angle of Attack (AOA) reaches a specified value. At this point, a constant angle of attack is maintained until the specified G level is again reached on the back side of the loop at which point G force is again held constant until straight and level flight is achieved. Thus, the maneuver can be logically described in terms of steady state parameters and transitions from one steady state to another. (Note: Rates can be and are also utilized as steady state parameters.) The approach taken closely parallels that arrived at independently in a study of undergraduate pilot training tasks and skills.[6]

The procedure and performance criteria identified in Appendix A reflect the TA-4J aircraft as utilized in the advanced jet training syllabus. Comparisons of the procedures and criteria utilized by the Readiness Instrument Training Squadrons (also flying TA-4 aircraft) were made. As expected, the criteria utilized in advanced jet training are more precise and demanding. The instrument training squadron utilizes basic and

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[6]Meyer, Robert P., Laveson, Jack I., Weisman, Neal S. and Eddowes, Edward E. Behavioral Taxonomy of Undergraduate Pilot Training Tasks and Skills: Taxonomy Refinement, Validation and Operations, Technical Report AFHRL-TR-74-33 (III), Air Force Human Resources Laboratory, Flying Training Division, Williams Air Force Base, Arizona, December 1974.

precision maneuvers for example, primarily for aircraft familiarization and verification of pilot skill level. As with the confidence maneuvers, the requirement is for smooth and safe aircraft handling rather than precise aerobatic performance. The goal of the readiness instrument flight training is to qualify the replacement pilot for instrument flight and not for aerobatics.

In summary, the syllabi for the four levels or phases of instrument flight maneuvers training were analyzed. The advanced jet training syllabus was selected for use in the study since it utilizes the broadest ranges of flight maneuvers, that were more precisely defined and included simulator training objectives. In addition, the syllabus maneuvers required, literally overlap all the other syllabi and thus, in fact, provide a comprehensive set of maneuvers for advanced training application demonstration. The detailed requirements are presented in Appendix A.

DEMONSTRATION CONSTRAINTS

The demonstration was implemented on the TRADEC system at the Naval Training Equipment Center. The system and the basic constraints involved have been reviewed in earlier studies of automated-adaptive training, e.g., Charles.[7] A sophisticated graphics display capability has been added with one display in the cockpit (mounted on the glare shield) and one at the operating console. In general, the constraints of importance to this demonstration include:

- no visual simulation capability
- no radio-NAV aids simulation
- F-4 flight equations

[7]Charles et al, op. cit., 1972.

- limited computing time (i.e., unused cycle time)
- limited computer memory

In addition, the existing graphics displays, printer, voice generation capability and simulator and computer operating consoles were utilized. These factors are not considered constraints on the demonstration results, but rather define the framework for the study. The TRADEC system is an R&D tool and provides a useful device for this type of study.

FUNCTION ANALYSIS

The design and implementation of the Basic Instrument Flight Maneuvers (BIFM) training package was systematically undertaken utilizing the advanced jet syllabus within the constraints of TRADEC. A basic system engineering approach was utilized. Following the requirements and constraints analysis, a function analysis was conducted. Figure 1 illustrates the basic functions involved. It reflects the demonstration requirements for:

(1) An expanded syllabus reflecting advanced jet instrument training requirements.

(2) Advanced performance measurements.

(3) Enhanced feedback techniques.

(4) Improved student records.

(5) An improved instructor interface.

These features, while within the state-of-the-art, represent new developments that require demonstration and in some cases validation to achieve training goals.

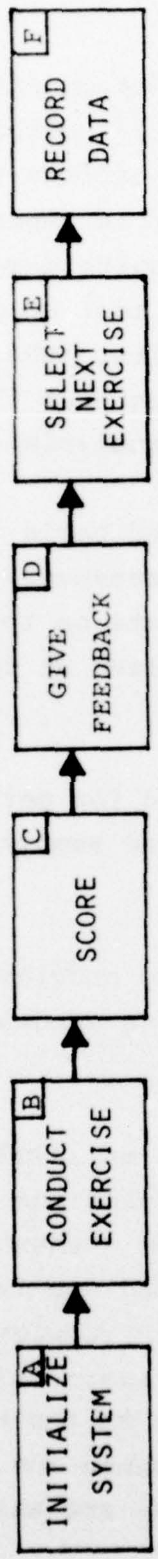

Figure 1. Basic functions.

A function analysis is a basic system design step. It becomes even more important when feasibility studies are involved, especially where the test platform differs significantly from the ultimate operational platform. It is important, for example, to identify the features which require demonstration or evaluation and to assess the impact of the test conditions (or the feasibility demonstration) on the results. The following sections review the system functions and function flow. Several assumptions are inherent in this function analysis.

Assumption (1) The student has acquired basic flight skills and is prepared for the instrument flight maneuvers stage of training. Thus, the training can concentrate on the instrument maneuvers and the exercises can be initialized at the instrument maneuver entry condition.

Assumption (2) The parameters required for performance measurement are readily available and can be sampled with the required accuracy.

Assumption (3) The simulation facility provides voice and graphics display capability for both the student and the monitoring instructor.

FUNCTION A. INITIALIZE. The first function involves the initialization of the system. Three sub-functions are involved. The first is concerned with identifying the student and creating or retrieving his training file. The second sub-function involves set-up of the system. This requires retrieval and implementation of the maneuver entry conditions. The third sub-function involves briefing the student on the training syllabus and in particular on the requirements for the next maneuver. The following initial conditions are assumed to exist:

(1) The simulator is functioning and all required equipment is operating or in a standby mode.

(2) The student is seated in the cockpit.

(3) The student has started the engines and established take-off configuration.

FUNCTION B. CONDUCT EXERCISE. This function is concerned with monitoring and scoring the students' performance. It begins with the unfreezing of the simulator and terminates at the end of the exercise with the freezing of the simulator. The following subfunctions are involved:

(1) Monitoring a brief "free" flight period while the student achieves satisfactory control of the aircraft and meets maneuver entry conditions.

(2) Detecting start of the maneuver.

(3) Initiating control and procedures monitoring and performance sampling.

(4) Detecting unacceptable control, crashes or completion of the exercise.

(5) Outputting of relevant data to the operator/instructor terminal.

(6) Freezing and resetting of the simulator after completion of the trial or a crash or exceeding the training envelope.

FUNCTION C. SCORE. The key to adaptive training is objective performance measurement and the generation of a score(s) for an algorithm for restructuring the course based on the measured performance. As demonstrated in the earlier studies of adaptive training, the measure(s) and score(s) required for this objective need only be effective in restructuring the syllabus to meet adaptive objectives. However, performance data are required for other training functions, namely, data for student feedback and for the instructor. Student feedback requirements include information both on error or mistakes and on progress towards the

criteria. The instructors' requirements are more extensive and include the information provided the student (with supporting data) as well as descriptions of his problems and control behavior. Thus, three types of performance data are required:

(1) Criteria oriented measures.

(2) Procedures oriented measures.

(3) Control input oriented measures.

The criteria measures address the variables that describe the tasks involved in operational terms.

Procedures measures address the variable that define the technique which should be employed in the execution of the task.

Control input measures address the variables that describe both the control strategy utilized and the perceptual-motor problems involved.

The three types of measures are obviously highly interactive but are essential to meet the three requirements of student feedback, instructor information, and adaptive syllabus control.

FUNCTION D. GIVE FEEDBACK. Providing knowledge of results to the student is basic to efficient learning. Two types of debriefing information are required. First, and most important, the student must know what he did wrong, particularly his procedural errors. For example, a loop cannot be successfully performed if entry speed is too low. The student who didn't know the proper entry speed might never be able to perform the loop regardless of the amount of practice. Thus, feedback on errors involving knowledge will be essential to instrument flight maneuver skill acquisition.

The second type of feedback involves providing information

about quality of performance. The value of this kind of feedback (knowledge of results) is well established. The distinction between "how to" (procedure) and "how well" (quality) is made primarily for practical reasons. These two types of feedback data are generated from different performance measures, i.e., "how to" feedback is derived from procedure measures and "how well" feedback from system and control scores.

FUNCTION E. SELECT NEXT EXERCISE. Adaptive training requires the adjustment of the exercise difficulty to meet the students' learning rate or progress. The syllabus must therefore be restructured on-line as a function of previous performance. The basic algorithm to accomplish this adjustment provides for both progression and regression through a detailed syllabus of increasing difficulty. Since instrument maneuvers require the integration of sub-skills, the adaptive syllabus actually took the form of a "nested" course where sub-syllabi are available for training in prerequisite sub-skills for each maneuver. The maneuver specification (Appendix A) outlines the maneuver elements and supporting skills.

Since the instrument syllabus consists of a sequence of precision and confidence maneuvers, the adaptive algorithm must insure criterion performance on each maneuver as well as precluding regression to already acquired maneuvers when they are not part of the supporting syllabus.

FUNCTION F. RECORD DATA. Three types of records are needed for effective automated adaptive training:

(1) Student performance record. A computer accessible record of student performance is necessary for adaptive control as well as for identification of the student and his status at the beginning of each training session.

(2) Student training records. A hard copy or other relatively permanent record of each student is required by the training activity.

(3) Debriefing data. Flight instructors normally debrief the student following each training session. Debriefing information ranges from annotated flight track histories to procedure and performance summaries. In addition, the instructor typically wants "memory joggers" to aid his critique of the students' performance.

While not identified as a separate function, overall training control is a basic function. Some of the many "housekeeping functions" which are necessary and implicit in the functions outlined in Figure 1 are:

(1) Determining end of training or session.

(2) Control of basic simulator including motion platform.

(3) Monitoring of aircraft configuration and subsystems.

(4) Interfacing with operator/instructor.

The details of the housekeeping function are specific to each training system.

Figure 2 is a system function block diagram of the advanced training package. A detailed analysis of the functional requirement was completed and a training function flow chart developed. Appendix B contains the basic and second level function flow.

DEMONSTRATION DESIGN

The demonstration system developed is reviewed in the following sections. The details are contained in the appendices. While the following paragraphs make the effort to appear as a

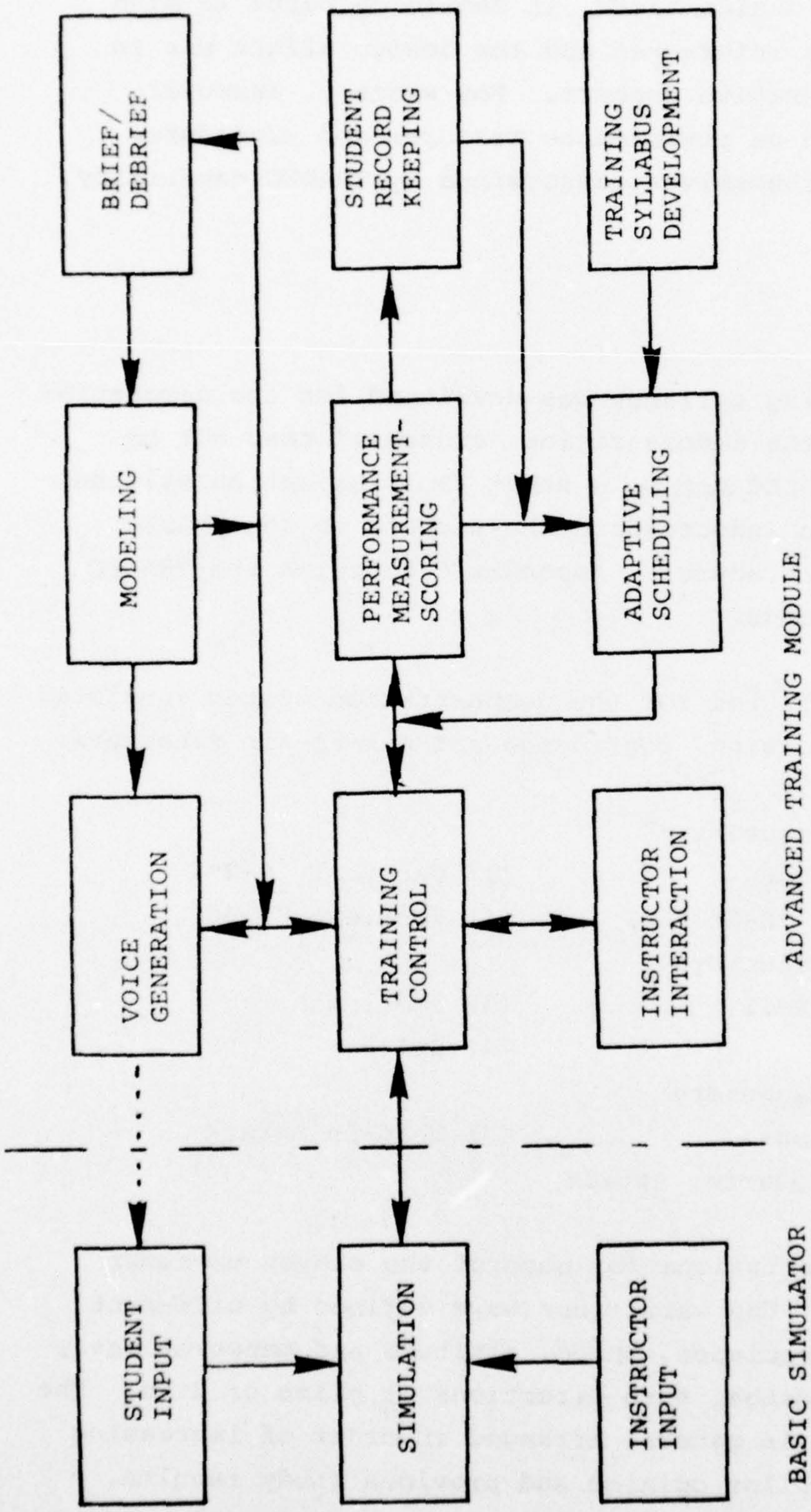

Figure 2. System functional block diagram.

sequence of discrete design tasks, it should be borne in mind that all of the tasks interacted and the design effort was in fact a single and iterative process. For example, maneuver segmentation depended on performance measures and procedures measures which were themselves constrained by TRADEC capability, etc.

SYLLABUS DESIGN

A detailed training syllabus was developed for the demonstration system. Since the demonstration "students" need not be familiar with the TRADEC System, a short familiarization syllabus was also developed to indoctrinate the student on the TRADEC cockpit and flight procedures. Appendix C contains the TRADEC familiarization syllabus.

The maneuvers selected for the demonstration system consisted of the following precision, confidence and air-to-air maneuvers.

a. Precision Maneuvers
   - (1) Turn Pattern
   - (2) Vertical "S-1"
   - (3) Vertical "S-2"
   - (4) Vertical "S-3"

b. Confidence Maneuvers
   - (1) Aileron Roll
   - (2) Loop
   - (3) Immelmann
   - (4) Split S

c. Air-to-Air Maneuvers
   - (1) Beam Attack
   - (2) Forward Quarter Attack
   - (3) Head-on Attack

A set of eight variations for each of the eleven maneuver types was developed. The variations were defined by different aircraft weights, turbulence, speed, altitude and maneuver entry direction, i.e., headings, turn directions or climb or dive. The eight variations are in general arranged in order of increasing difficulty based on pilot opinion and previous study results. Appendix C contains the complete syllabus. Appendix F describes the controller model used in the air-to-air maneuvers.

The performance measurement technique, developed and discussed in the following pages, involved the segmentation of the maneuvers. One of the results of this approach was a means of identifying student problem areas. Thus, it becomes possible to isolate the procedural or control problems being experienced by the student. This generated the need for a supporting or part-task/maneuver sub-syllabus. The overall approach is discussed in detail in the following paragraphs. However, a sub-syllabus was developed which consisted primarily of basic flight maneuvers. It included:

(1) Straight and Level Flight
(2) Climbs and Dives (C&D) - constant speed
(3) Climbs and Dives (C&D) - constant rate
(4) Turns - constant bank angle
(5) Climbing and diving turns
(6) Inverted flight.

Again as in the main syllabus, a set of eight variations arranged in general increasing difficulty order comprise the syllabus. Similar difficulty factors were utilized. Appendix C contains the complete sub-syllabus.

PERFORMANCE MEASUREMENT

The detailed analysis of the maneuvers included the performance criteria for each maneuver and the procedures involved. The latter was in effect, a task-sequence analysis. It became clear from these data that effective measurement of the students' performance in the maneuvers would require consideration of both cognitive and psycho-motor aspects. Furthermore, automated syllabus restructuring could probably not be effectively accomplished unless the students' flight problem(s) was isolated. For example, the student could probably never master a maneuver if he did not know the correct entry speed or the proper "lead-

time." Thus, the need to isolate or diagnose the nature of the performance problem, as well as to identify criterion performance, led to considering the following three aspects of student performance.

(1) knowledge of procedures
(2) control skill
(3) task performance

The measures provide a means of establishing that the student:

- knew what to do
- knew how to do it
- had achieved the required level of performance

The implications for adaptive scheduling are obvious. If the student does not know how to perform the maneuver, additional practice or trials will probably result in learning incorrect performance. He must be given information on how to perform it, rather than additional practice. Oppositely, if he is performing the maneuver correctly but not at criterion level, additional practice is required. If the performance problem is specific to a particular portion of the maneuver, additional part-task practice should probably be scheduled. In short, it became clear that at least three measures of student performance would be required and if properly designed, could provide the insight needed for adaptive training and feedback.

Analysis of the measurement requirements also indicated the need for sub-dividing each maneuver into meaningful performance segments. Such segments turned out to be those identified in the procedure or task sequence analysis. This segmentation also met the requirements for a reasonable time period for measurement and for well defined steady state and transitions parameters

to detect segment start and end. The Turn Pattern will be used to illustrate the approach and the results.

Table 2 lists the procedures for the Turn Pattern as developed in the requirements analysis (TA-4J aircraft - Advanced Jet Syllabus). The turn pattern consists of turns and reversals at 30°, 45°, and 60° of bank for 60°, 90°, and 180° of heading change respectively.

TABLE 2. TURN PATTERN PROCEDURES

(Advanced Jet Syllabus)

a. Three seconds before start of maneuver, roll into 30° bank.

b. Adjust nose and power to maintain speed and altitude.

c. Adjust bank angle.

d. At 54° of turn, reverse bank.

e. Check straight and level passing 60° of turn.

f. Adjust nose and power to maintain speed and altitude.

g. After 54° of turn, reverse bank to 45°.

h. Check straight and level at original heading.

i. Check bank angle, adjust nose and power to maintain speed and altitude.

j. After 81° of turn, reverse bank.

k. Check straight and level at 90° of turn.

TABLE 2. TURN PATTERN PROCEDURES (cont.)

l. Check bank angle, adjust nose and power to maintain speed and altitude.

m. After 81° of turn, reverse bank to 60° of bank.

n. Check straight and level passing 0° of turn.

o. Check bank angle, adjust nose and power to maintain speed and altitude.

p. After 168° of turn, reverse bank.

q. Check straight and level passing 180° of turn.

r. Check bank angle, adjust nose and power to maintain speed and altitude.

s. After 168° of turn, return to level flight.

t. Check straight and level at original heading, adjust nose and power to maintain original speed and altitude.

It is obvious that events a, d, g, j, m, p and s are transition onset points, i.e., change of bank angle points. Events b, f, i, l, o, r and t are steady state segments for which measurable parameters can be readily identified, e.g., speed, altitude and bank angle.

Further analyses were conducted to establish the feasibility of practically detecting segment onset and termination. Table 3 shows the resultant segmentation for the Turn Pattern.

Except for the first segment which is time based and the second which is bank angle based, the rest of the segments are all heading based and reflect the lead time requirement for the

turns, i.e., 6° for the 30° bank, 9° for the 45° bank, and 12° for the 60° bank.

TABLE 3. TURN PATTERN SEGMENTS

SEGMENT NO.	TITLE	START	STOP
1	Gate	-15 sec	0 sec
2	Entry	0 sec	$\phi > 25^{\circ}$
3	30° Bank	$\phi > 25^{\circ}$	054°
4	Reversal	054°	054°
5	30° Bank	054°	006°
6	Reversal	006°	009°
7	45° Bank	009°	081°
8	Reversal	081°	081°
9	45° Bank	081°	009°
10	Reversal	009°	012°
11	60° Bank	012°	168°
12	Reversal	168°	168°
13	60° Bank	168°	012°
14	Roll Out	012°	000°

Specific procedures are also readily identified. For example, in Table 2,items a, d, g, j, m, p, and s all identify lead time requirements so that the aircraft can be straight and level at the exact turn requirement (e.g., e, h, k, n, q and t).

Segment 1 is in effect a "gate" condition check which establishes that the student has control of the aircraft at the assigned speed, altitude and heading and is straight level. It also verifies that the student has not prematurely initiated the maneuver (which begins at "zero" time) and that he is in the correct position to initiate the maneuver. Procedure checks at segments 2, 4, 6, 8, 10, 12 and 14 are similar in that they

provide a check for completion of the exact turn required, i.e., the aircraft is approximately level in the reversal at the desired heading change (i.e. $\phi = 0$ at $\Psi = 60^{o}$, 90^{o} or 180^{o} of change). Tolerance bands of 5^{o} on bank and 2^{o} on heading were established to insure a data sample by the computer system. Although performance evaluation will be discussed in later paragraphs, the simplicity of detecting student procedural problems based on the checks listed above should be pointed out. Failure to achieve criterion maneuver performance (defined in later sections) because of turn undershoot or overshoot, for example, can be easily identified. Table 4 illustrates the procedure segmentation for the Turn Pattern.

TABLE 4. TURN PATTERN PROCEDURE SEGMENTS

SEGMENT NO.	SAMPLE INTERVAL	KEY PARAMETER	LIMITS
1	-5 to 0 seconds	h_e	±200 ft
		V_e	± 20 kts
		$\dot{h}$	±500 ft/min
		ψ_e	$\pm 10^{o}$
		ϕ_e	$\pm 5^{o}$
2	0 to 3 seconds	$\lvert\phi\rvert$	$>5^{o}$
4	$-5^{o}<\phi<5^{o}$	$\lvert\psi\rvert$	058^{o} to 062^{o}
6	"	"	358^{o} to 002^{o}
8	"	"	088^{o} to 092^{o}
10	"	"	358^{o} to 002^{o}
12	"	"	175^{o} to 185^{o}
14	"	"	358^{o} to 002^{o}

Performance measures for the maneuvers were established from the requirements analysis and the segmentation analysis. As discussed earlier, the latter reflects steady and transition parameter states. Two types of measures were sought (in addition to procedures measurement), one which reflected psycho-

motor skills requirement and one which measured task or maneuver or "system" performance. Three control parameters were sampled to measure psycho-motor performance. They are sideslip (β), aileron stick input (Stick A) and elevator stick input (Stick E). These parameters were selected on the basis of earlier studies. A root mean square (RMS) transformation was also selected. (Note: many other transforms were programmed and are available in the system.)

Task or maneuver performance was measured in terms of key steady state parameters for each segment. The parameters were identified both in the requirements analysis and the segmentation analysis. The parameter sampled by segments for the Turn Pattern are listed in Table 5.

TABLE 5. TURN PATTERN SYSTEM PERFORMANCE MEASURES

SEGMENT NO.	PARAMETERS h_e	V_e	ψ_e	t
1	-	-	-	elapsed
2	rms	rms	-	"
3	"	"	rms	"
4	"	"	-	"
5	"	"	rms	"
6	"	"	-	"
7	"	"	rms	"
8	"	"	-	"
9	"	"	rms	"
10	"	"	-	"
11	"	"	rms	"
12	"	"	-	"
13	"	"	rms	"
14	"	"	-	"

Table 5 reflects the obvious Turn Pattern requirements, i.e:

(1) The pattern is flown at constant altitude.

(2) The pattern is flown at constant airspeed.

(3) Constant bank is maintained on each turn segment.

In addition, for each segment, elapsed time was periodically monitored and compared against a nominal segment time. The difference was used as both a performance measure and a time-out criterion. In the latter case, if the elapsed time exceeded the nominal segment time by a predetermined amount, the maneuver was automatically aborted.

Finally, three separate scores were computed, namely:

a. System Score (maneuver performance).

b. Control Score (psycho-motor performance).

c. Procedures Score (cognitive performance).

The system and control scores were computed as weighted means. In each case an individual segment score was computed that was the sum of the weighted parameters divided by the number of parameters measured for the segment. Next, a system or control score was computed that was the sum of the weighted segment scores divided by the number of segments. Weights were arrived at empirically and in general reflected a normalizing function. They are contained in Appendix C.

The procedure score was computed differently. The measure for each procedure was discrete; zero if the procedure was missed, and one if the procedure was accomplished. The overall procedure scores were averaged, i.e., the segment scores were summed and divided by the number of segments. Appendix C reviews the performance calculation in detail.

The maneuver segmentation, procedure measures, performance measures (system and control) sampling times and rates for each maneuver are also contained in Appendix C.

To summarize, measures were developed to sample three aspects of student performance; psycho-motor performance, cognitive performance and task performance. The maneuvers were segmented based on the maneuver requirements analysis and implementation problems (segment start and end detection). Maneuver procedural requirements were identified by segments as were parameters to be measured. In general, the segments divided the maneuvers into periods of steady state and of transition from one steady state to another steady state. Most procedural requirements occur in the transition segments. The specific transition techniques were identified in the maneuver analysis. The measures were used to diagnose student problems and for use in performance evaluation and adaptive syllabus development.

ADAPTIVE SYLLABUS DESIGN

The operational instrument maneuvers syllabus presented several new problems in creating an individualized syllabus not considered in the earlier studies. One such problem was the relative discrete characteristic of each maneuver. Thus, performance problems in the Loop, for example, could probably not be solved by arbitrarily sending the student "back" to the Aileron Roll or to a vertical maneuver. While generally, the syllabus represents increasing skill requirements in terms of complexity and required integration, with few exceptions, the maneuvers are not closely related and the syllabus location order could be somewhat arbitrarily changed. The exceptions are obvious. The Vertical S-1, S-2, S-3 form a natural sequence. The Immelmann and Half Cuban Eight logically follow from the Loop. However, even in these sequences, specific performance problems cannot necessarily be solved by practicing directly

preceding maneuvers. Each maneuver contains some new control tasks. If the student experiences difficulties in these new tasks, a different approach to adapting the syllabus is required. This problem is considered typical of operational training requirements.

The need for recognition of student performance problems was established early in the study. The segmentation and performance measurement approaches reflected this prerequisite for implementing adaptive training. Specifically, the basic requirement was to be able to identify the nature of the problem and where it occurred. The first was partially solved by broadly separating "procedural" or cognitive type problems (what to do and how to perform it) from psycho-motor skill problems. The second was solved with the maneuver segmentation approach. Thus, it was possible, at least generically, to identify the type of problem, the location and control task involved. This formed the basic input for the adaptive syllabus algorithm.

As discussed in preceding paragraphs, each maneuver in the syllabus consisted of eight different flights arranged in approximate order of increasing difficulty. Previous studies had shown that starting at the lowest level of a maneuver group was not optimum since the rapid learner or partially qualified student was retained in the group longer than required while the students who experienced difficulty were forced to repeat the same level exercise. Therefore, entry into each maneuver was set at level five (of eight levels). This provided sufficient latitude both to reliably establish achievement of criterion performance and to evaluate performance problems. It also permitted some modifications of the adaptive algorithm that were indicated by the earlier studies. These studies had shown that regression in the syllabus should be reduced.

The overall syllabus control logic developed provides the following:

(1) Entry at mid-point of maneuver group (level five of eight levels).

(2) Differential syllabus restructuring as a function of the three performance scores, i.e., system score, control score and procedure score.

(3) Automated prompting (instructor model) at levels one through five.

(4) Return to a specific basic instrument maneuver sub-syllabus based on performance analysis.

Figure 3 summarizes the basic function flow for syllabus control. The adaptive logic flow is contained in Appendix B.

Entry to the sub-syllabus occurred after a repeated decrement from the adaptive logic algorithm at level one for the maneuver. After two "failures" at the simplest level, the control logic selected the segment on which the student had the most difficulty, i.e., the poorest performance scores and then selected the sub-syllabus which supported that segment. Entry to the sub-syllabus was also at level five. Mastery of the sub-syllabus resulted in return to the maneuvers failed earlier and entry at level one.

FEEDBACK DESIGN

Feedback was provided to the student during the maneuver, at the end of each maneuver and at the conclusion of each training session. The medium utilized was largely determined by the capability of the TRADEC system. The cockpit display was utilized to display performance scores at the conclusion of each trial. Appendix D reviews the cockpit display.

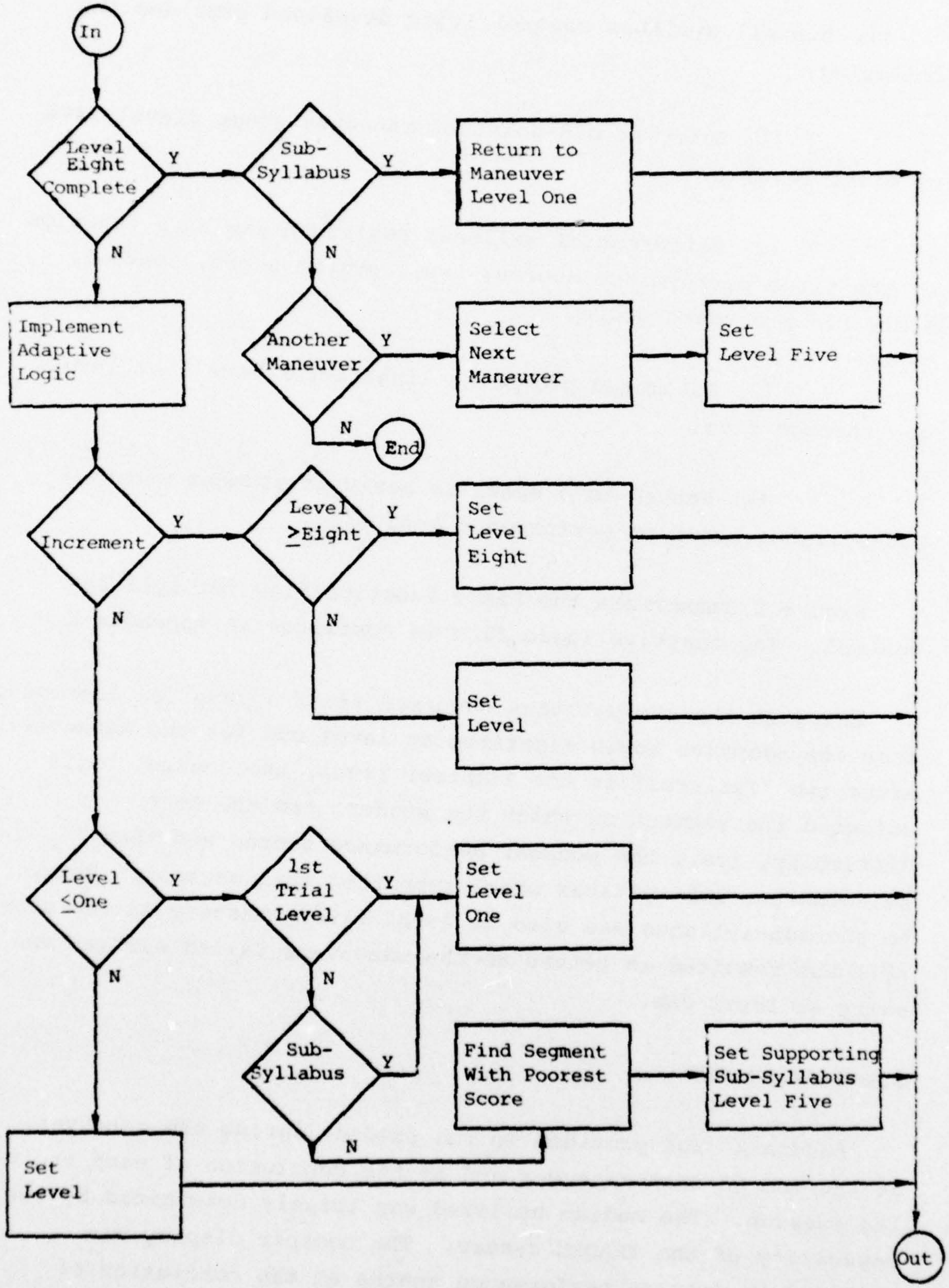

Figure 3. Syllabus control function flow.

The speech system was utilized to provide feedback during the flight. The model of the basic instructor functions developed in the earlier studies was utilized. In general, the model provides for alerting the student to a parameter "out-of-tolerance" and directing corrective action when the parameter error exceeds acceptable levels. The model was implemented for all maneuvers whenever the difficulty level dropped below level six. Appendix D reviews the audio instruction implementation.

The instructor display provided plots of key parameters. Appendix D reviews the instructor's display. The display provided the instructor information for evaluating student behavior.

Extensive hard-copy data for each trial were provided. The details of the record are contained in Appendix D. The format was dictated by the demonstration objectives and far exceeds the needs for operational training. The hard-copy data were used by the instructor for debriefing both after the trial and at the end of the training session.

STUDENT DISPLAY

A graphics CRT display in the TRADEC cockpit was utilized to brief the student on the maneuver and the specific characteristic of the next trial. The latter was important since minor departures from maneuver requirements that were part of the syllabus could significantly affect performance scores, e.g., turning to wrong initial heading. The display consisted of a simplified line drawing of the maneuver along with key flight parameter values. The display appeared as soon as initial conditions had been set. The student studied the display while the system was trimming the aircraft. When trimmed, the student was directed to take control. After 10 seconds of "free flight" a one-minute "clock" appeared in the upper left corner of the display with the hand at the 9 o'clock position, indicating 15

seconds to go to the start of the maneuver (at 0 time or 12 o'clock). At -15 seconds, a "15 seconds to go" message was also provided by the speech system. A second message at 5 seconds, "5 seconds to go" was also output. It corresponded to the start of the first segment of the maneuver.

The display was also utilized to provide feedback data as discussed in the preceding section.

INSTRUCTOR CONSOLE

An instructor console was developed within the constraints of the TRADEC system. It utilized the TRADEC operating console, two graphic displays and the computer operating console and printer. Although the physical arrangement was far from optimum, the basic functional interface for an instructor was available.

One display duplicated for the instructor the image provided to the student in the cockpit. In the off-line mode, it also provided the means for altering the student's display.

A second graphic display provided the instructor with X-Y plots of key maneuver parameters as well as student file data. Appendix D reviews this display.

The basic TRADEC and computer consoles have been described in the earlier reports.

STUDENT RECORDS

Provisions were made to maintain two types of student records. One was maintained in computer memory. It provided a complete training record of the student in terms of identification, syllabus status and history. All data necessary to control the syllabus were retained. The second student record

was output by the printer. Appendix D contains a sample of this record. Detailed performance data for each segment were included as well as maneuver requirements and overall performance data and scores. The record was output during the trial, i.e., data on each segment were output at the end of the segment.

OTHER SUB-SYSTEMS

The implementation of the instrument flight maneuvers syllabus demonstration on the TRADEC system, as an automated and adaptive training package, also required the design and development of supporting modules or sub-systems. While some will be required for operational training, some are unique to the TRADEC design. In general, the software to implement the function flow presented in Appendix B is modular in design and thus, except for specific TRADEC software interfaces, should be transferable to operational trainers. Several features are unique to TRADEC or TRADEC-like simulators. Safety/abort limits, power plant initialization and aircraft trimming are examples. The safety/abort limits are discussed in Appendix D. Power plant initialization requires directing the student to advance (or retard) the throttles to a fixed RPM which will conform to the initialized power conditions. In the "Freeze" mode, power or engine simulation is under computer control. However, since the throttles are not controllable by the program, the engine simulation returns to the control of the throttles when the simulator is "unfrozen".

Aircraft trim in the TRADEC must be accomplished indirectly and slowly to avoid disrupting vehicle simulation. It obviously must also be accomplished at initialized power settings. Thus, a unique sequence of initialization, throttle adjustment and aircraft trimming must be accomplished if the TRADEC is to be released to the student in a relatively stable condition.

The computer controlled voice generation sub-system available on the TRADEC was used. This particular unit is constraining in terms of vocabulary. It is described in detail in earlier reports. Appendix D contains the vocabulary available in the demonstration system.

AIR-TO-AIR TRAINING

The application of the segmentation and performance measurement techniques to a weapons training task was conducted as a final task. The original study[8] involved a relatively simplistic model of the attack situation. Therefore, an improved simulation model was implemented, and maneuver segmentation and multiple performance techniques incorporated. Appendix F contains the syllabus and other program modifications required to implement air-to-air automated-adaptive training.

DEMONSTRATION

Both the instrument flight maneuver and the air-to-air packages were demonstrated utilizing subject "students" available at the Naval Training Equipment Center. All features of the program were exercised and they performed as expected. Some of the weighting factors and constants were adjusted during the checkout and demonstration. However, the final values must await implementation in an actual training program since they are partially a function of vehicle, student and instructor characteristics as well as dependent on performance objectives.

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[8] Charles et al, op. cit., 1973.

SECTION V
DISCUSSION

APPROACH

As in the earlier studies, a systems engineering approach proved not only effective, but essential to the development of a demonstration system. The initial definition of requirements and constraints is particularly critical to this type of task, especially in revealing and in structuring designs for the governing or relevant variables. The operational syllabi reviewed were found to contain (although sometimes it was obscured) the basic data required for developing a detailed automated/adaptive syllabus. The performance criteria, while not explicitly stated were developed from supporting documentation (Flight Training Instructions) and interviews with the training staff. While some of the criteria may need further validation in terms of fleet requirements, the objectives developed are internally consistent and sufficient for training program development. Four other techniques developed in the study utilizing the system engineering approach will be discussed. They are:

(1) Task segmentation.

(2) Performance measures.

(3) Sub-syllabi development.

(4) Syllabus control.

They represent the major changes developed to implement the operational instrument maneuvers syllabus as specified for Advanced Jet Training.

SEGMENTATION

The earlier studies of automated adaptive training had

utilized only system performance for syllabus structuring. While obviously correlated with student behavior and thus useful for adaptive syllabus control, it was recognized that more refined measures would eventually be required if the syllabus was to be adapted to student performance difficulties. Some diagnostic capability would be essential. However, any but the simplest of flight tasks involves a complex sequence of control tasks that have cognitive aspects, especially for original skill acquisition. The analysis of the maneuvers led to three sets of conditions:

Condition One. Steady State Maneuver Parameters.

Condition Two. Steady State Segment Parameter.

Condition Three. Transition State Parameters.

The first condition reflects general system performance objective. They are the broad envelopes in which the maneuver must be performed. For example, the Turn Pattern is conducted at fixed altitude and speed and little sideslip.

The second condition reflects specific control parameters for the maneuvers, i.e., those parameters that govern the maneuver. For the Turn Pattern, these parameters are Bank Angle and Heading. The governing parameters are static for a specified time and are measurable. The maneuver analysis revealed that all maneuvers contained steady state segments with governing parameters essential to the maneuver and which should represent learning objectives.

The third set of conditions involved the transition of the governing parameters from one steady state to another. Since a dynamic change in these parameters is occurring, the performance measures for this condition were found to be highly procedural in

content and thus more cognitive as opposed to psycho-motor in nature. Analyses indicated that the procedures could be identified and performance requirements established.

Measures were developed, which though discrete, assessed procedure accomplishment. For all these conditions, measures were found that detected onset and completion of the segment without overlap of segments or confusion as to the segment involved. The latter is particularly important to automated training control.

Thus, a technique for segmenting flight tasks was developed to meet performance measurement requirements which resulted in also providing improved automated control. To further facilitate control, nominal durations were computed for each segment. These times provided additional criteria for positive training control. Excessive time in a segment (without triggering the segmented condition) created a "time-out" condition which resulted in aborting the trial. While a factor of twice nominal was utilized, the "time-out" criteria should reflect relative duration as well as importance to the maneuver.

PERFORMANCE MEASUREMENT

The three performance measures proved effective and opened a new approach to syllabus control. In particular, the separation of procedures and psycho-motor performance from total task or system performance established the feasibility of at least crudely identifying the students performance problem. Although the data were not exploited for adaptive syllabus structuring in this study, the approach should permit improved adaptive training by providing the basis for generation of a specific remedial sub-syllabus. For example, procedures failures could lead to a procedures training sub-syllabus and control problems to special control coordination exercises. While the data collected during

checkout and demonstration are too limited for conclusions, it does suggest that, in fact, procedures performance must be mastered if criterion performance is to be achieved and probably before control performance reaches criteria related levels. Intuitively, the sequence is appealing and appears to correspond to "good" instructor technique.

SUB-SYLLABUS DEVELOPMENT. The advanced jet maneuvers analysis included indentification of supporting basic maneuvers, i.e., other maneuvers in which proficiency was considered essential or highly related to the advanced maneuver. The supporting maneuvers were identified either in the advanced syllabus, the supporting Flight Training Instructions, or through instructor interviews. However, these supporting maneuvers did not always relate to the segmentation which was subsequently developed. For example, a basic inverted flight maneuver was required for the Loop set of maneuvers, especially the Immelmann and Half Cuban Eight.

While an existing basic jet flight maneuver was selected for the sub-syllabus support for most segments, the structure of the supporting syllabus is not considered optimum. The diagnostic capability of the performance measures allowed for part-task exercises, a function usually performed in flight by the instructor, but rarely defined in the syllabus or implemented in an operational flight trainer. This highly individualized training specifically oriented to student problems is not possible based on a single score. The capability to isolate and identify the student's problems in terms of maneuver segments and procedure and control scores developed in this study may permit an automated approach to problem-oriented adaptive training.

SYLLABUS CONTROL. The design of the syllabus restructuring and overall control included the need for instructor interaction. Since instructors were not available or "simulated" in the demon-

stration, the success of the interface design cannot be evaluated. However, the impact of the supporting syllabus and performance measurement concepts on syllabus control and the interface designed can be reviewed. Two effects stand out. First is the adaptive logic routine which as designed requires exiting from the maneuver syllabus only at level one and always returning to level one. The significance and success of the procedures performance measures was not anticipated. As a result, the syllabus control or adaptive logic was designed to reflect overall task performance more than procedures or sub-task performance. Thus, "failure" was defined as maneuver failure after which procedure performance was analyzed. The limited data suggest that procedures failures might be effectively used to restructure the syllabus directly, especially with the instructor pilot's capability to monitor and interact with the training controller. Thus, procedures failures could result in "freezing" of the trainer, analysis of the problem, and branching to specific supporting subsyllabus. The approach would be desireable from a training viewpoint in terms of early detection of error performance, prompt feedback, and remedial training. The capacity of a computer system to store or restructure a unique remedial syllabus could be exploited and could result in syllabus complexity far beyond the capability of the training staff or instructor pilot to duplicate or exercise. Yet, an efficient instructor interface would permit effective instructional management and any adjustments to the training evaluation.

The second effect relates the quantity of information available to the instructor pilot (IP) and the increasing complexity of the control program. The data output for the demonstration went far beyond the requirements of training or an IP's capability to assimilate it. Two aspects are involved. One relates to the quantity of information being generated about student behavior, the second to the status and mode of operation of the training system at any time.

Student performance data were output for each segment and consisted of at least seven parameters for each segment. The demonstration data included a complete printout of expected values, type of transform, raw measure, weighting factor, parameter score type of measure, and overall segment scores. While much of these data can be deleted in an operational system, further consolidation would be required, especially in terms of instructor functions. Since printed data were not directly accessible at the simulator operating console, the integration of hard copy data, simulator console data, and graphics display could not be evaluated.

Related to the problem of student performance data is system status. While the graphics displays proved adequate for system status information, expanded use of procedural or control performance scores with the segmentation approach may require enhancement of the displays, especially in terms of impending instruction decision points and alternative events. Freezing on procedural errors or freezing of parameters for sub-syllabi, for example, will require a new approach to instructor display design if the instructor is to have any opportunity to evaluate system training actions in real time. Again, the major impact is on the potential use of the expanded performance measurement and individualized syllabus possibilities. Automating the training operation to an equivalent or greater extent than done here does not pose a problem. Providing the IP information to stay abreast of the evolution does pose a new problem.

SECTION VI
CONCLUSIONS

The study was concerned with exploring the mutual impact of operational syllabi and automated-adaptive training technology on ground based aviation training. The earlier successful technical demonstrations of automated-adaptive training had left unanswered implementation problems created by the nature of actual training syllabi and instruction functions. This study has resulted in some definitive answers to the problem and exposed several new design tasks and feasible solutions.

CONCLUSION 1. Operational syllabi and training operations provide sufficient data to design and implement automated-adaptive training capability for ground based trainers such as Operational Flight Trainers.

CONCLUSION 2. Performance measures which sample knowledge, control skill and task performance are feasible and lead to the capability of diagnosing the characteristics of the students' performance acquisition problems.

CONCLUSION 3. Construction on-line of an individualized <u>and</u> remedial syllabus based on the type of performance problem encountered by the student is feasible.

CONCLUSION 4. Further integration of the instructor into the training system will be required if computer assisted performance problem diagnosis and remedial syllabus generation are to be exploited.

CONCLUSION 5. Segmentation of complex pilot training tasks for computer syllabus control is feasible and provides a logical breakdown of performance measurement and data for the analysis of learning problems.

SECTION VII
RECOMMENDATIONS

The study of the impact of operational training requirements on advanced training techniques resulted in the development of several new approaches to automated-adaptive training. Therefore, the recommendations that follow reflect both the results of that study and demonstration and the implication of the new developments.

RECOMMENDATION 1. The translation of operational syllabi and training objectives for advanced jet instrument flight training has proven feasible. It is recommended that the approach be evaluated on an Operational Flight Trainer (Device 2F90).

RECOMMENDATION 2. The feasibility of diagnosing the type of performance problem and where it occurred within the segment was demonstrated. It is recommended that a multi-component scoring algorithm for syllabus control be further explored. The design and demonstration suggest the potential usefulness of sub-syllabi to support the student's training needs in terms of specific cognitive, psycho-motor task problems. Syllabus restructing can be controlled by the relevant performance measures developed in the study.

RECOMMENDATION 3. The use of parameter(s) freeze (forcing a specified parameter(s) to maintain a constant value throughout the maneuver) should be explored as part of the study included under Recommendation 2. Although not part of the present study, the checkout phase utilized the technique under manual control with some effectiveness. The task requirements analysis, segmentation technique and performance measurement approach should contain the data required to identify the parameters that could or should be frozen to aid training.

RECOMMENDATION 4. An evaluation of the student briefing and feedback concept should be conducted. The concept developed is feasible and appears to be effective. However, no student training was acutally conducted.

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APPENDIX A
ANALYSIS OF INSTRUMENT SYLLABUS
(ADVANCED JET TRAINING)

INTRODUCTION

A detailed analysis of basic instrument flight maneuvers was essential to the design of an automated-adaptive training package for implementation on flight trainers or simulators. The analysis identified quantitatively the characteristics of the maneuvers, the basic supporting maneuvers supplied, the flight procedures required and the performance criteria involved. Characteristics include entry condition, e.g., altitude, speed, heading, attitude, maneuver transition points and parameters, and terminal conditions to be achieved. Procedures refer to the basic sequence of tasks the student must perform to complete the maneuver. The basic supporting maneuvers designate the exercises that contain the prerequisite skills. Performance refers to the skill level indicated or required by the training acitvity or operational unit. The performance criteria reflected system performance, i.e., both student and aircraft and thus, distinguished from measures only of student performance or of vehicle performance. In automated-adaptive training design, as with other training techniques, system performance criteria are utilized primarily for "pass" or "completion" purposes.

MANEUVERS

The following maneuvers are part of the advanced jet syllabus. They have been categorized in terms of precision, confidence and other maneuvers.

I. PRECISION MANEUVERS

A. Turn Pattern
B. Vertical "S-1" Pattern
C. Vertical "S-2" Pattern
D. Vertical "S-3" Pattern
E. Penetration Pattern

II. CONFIDENCE MANEUVERS

A. Aileron Roll
B. Wingover
C. Barrel Roll
D. Loop
E. Half Cuban Eight
F. Immelmann
G. Split-S
H. Squirrel Cage

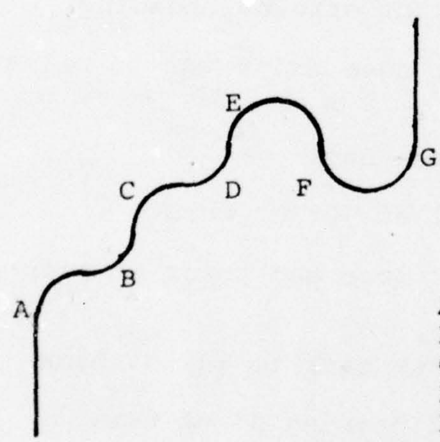
III. OTHER MANEUVERS

A. Approach to Stall
B. Unusual Attitude

I. PRECISION MANEUVERS

A. Turn Pattern

1. Description. The turn pattern is a series of reversing turns at different bank angles. The pattern begins in level flight at 300 KIAS at 10,000 feet. The pattern is flown at constant speed and altitude. The first turn is a 30° bank for 60° of turn followed by reversal to original heading. Heading is again reversed but with a 45° bank for 90° of turn followed again by reversal to original heading. Finally, heading is reversed with a 60° bank for 180° degrees of turn followed by reversal to original heading. Figure 4. portrays the maneuver.



A. 30° Bank for 60°
B. 30° Reverse Bank for 60°
C. 45° Bank for 90°
D. 45° Reverse Bank for 90°
E. 60° Bank for 180°
F. 60° Reverse Bank for 180°
G. Straight and Level 10,000'

Figure 4. Turn Pattern

2. Basic Supporting Maneuvers

a)	Entry	Straight and Level Basic Transitions
b)	Maneuver	Constant Angle of Bank Turns

3. Procedure

a) Three seconds before start of maneuver, roll into 30° bank

b) Adjust nose and power to maintain speed and altitude

c) Adjust bank angle

d) At 54° of turn, reverse bank

e) Check straight and level passing 60° of turn

f) Adjust nose and power to maintain speed and altitude

g) After 54° of turn, reverse bank to 45°

h) Check straight and level at original heading

i) Check bank angle, adjust nose and power to maintain speed and altitude

j) After 81° of turn, reverse bank

k) Check straight and level at 90° of turn

l) Check bank angle, adjust nose and power to maintain speed and altitude

m) After 81° of turn, reverse bank to 60° of bank

n) Check straight and level passing 0° of turn

o) Check bank angle, adjust nose and power to maintain speed and altitude

p) After 168° of turn, reverse bank

q) Check straight and level passing 180° of turn

r) Check bank, adjust nose and power to maintain speed and altitude

s) After 168° of turn, return to level flight

t) Check straight and level at original heading, adjust nose and power to maintain original speed and altitude

4. Performance Criteria

	Qualified	Conditionally Qualified	Unqualified
a) Bank Angle	±2.5°	±5°	>±5°
b) Airspeed	±10 KIAS	±20 KIAS	>±20 KIAS
c) Altitude	±100'	±200'	>±200'

5. Difficulty Variables

a) Aircraft speed

b) Aircraft weight

c) Turbulence

d) Partial panel

B. Vertical "S-1" Pattern

1. Description. The vertical "S-1" pattern is a constant airspeed and constant heading series of descents and climbs of 1,000 feet (Figure 5.) The standard "S-1" consists of two climbs and two descents completed in four minutes. In the TA-4J, the pattern is flown at 250 knots and 1,000 feet per minute rate of climb or descent. Power is used to control vertical speed and nose attitude to control airspeed. Transitions to climbs or descents are lead by an altitude equal to 10% of the rate of climb or descent. (100 feet in this case.)

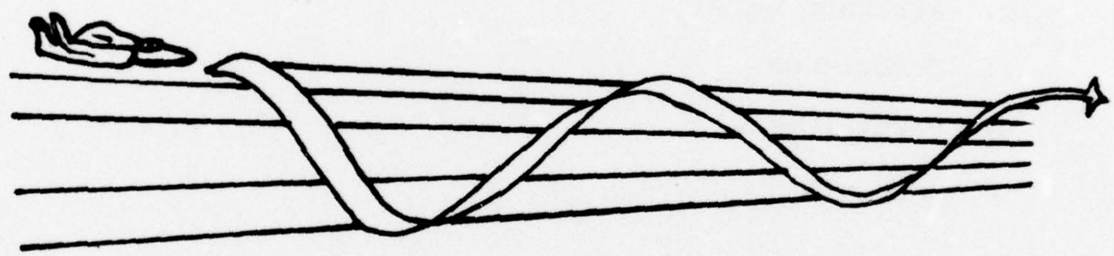


Figure 5. "S-1" Pattern

2. Basic Supporting Maneuvers

a)	Entry	Straight and Level Level Speed Changes
b)	Maneuver	Constant Rate of Climbs/Desc. Basic Transitions

3. Procedure

a) Three seconds prior to start, reduce power to about 80%, lower nose to about -3°.

b) Adjust attitude and throttle to maintain 1,000 feet per minute rate of descent and 250 KIAS.

c) Maintain heading.

d) Three seconds or 100 feet before end of descent, increase power to about 92% and raise nose to about +3°.

e) Adjust attitude and power to maintain 1,000 feet per minute climb and 250 KIAS.

f) Maintain Heading.

g) Three seconds or 100 feet before original altitude, decrease power to about 80% and lower nose to -3°.

h) Repeat b).

i) Repeat c).

j) Repeat d).

k) Repeat e).

l) Repeat f).

m) Three seconds or 100 feet before original altitude, decrease power to about 85% and lower nose. Maintain heading, altitude and 250 KIAS.

4. Performance Criteria

	Qualified	Conditionally Qualified	Unqualified
a) Heading	±2.5°	±5°	>±5°
b) Airspeed	±10 KIAS	±15 KIAS	>±15 KIAS
c) Vertical Speed	±100 fpm	±200 fpm	>±200 fpm
d) Transition Altitude	±100'	±200'	>±200'

5. Difficulty Variables

a) Aircraft Weight

b) Turbulence

c) Aircraft Speed

d) Partial Panel

C. Vertical "S-2" Pattern

1. Description. The vertical "S-2" is a "S-1" pattern incorporating a one-half standard rate turn which is maintained during the climb and descent. Each 90 degree of turn is completed in each descent and climb. Constant airspeed and vertical speed are employed. The maneuver is entered at 250 KIAS, clean at 10,000 feet of altitude. Figure 6. portrays the manuever.

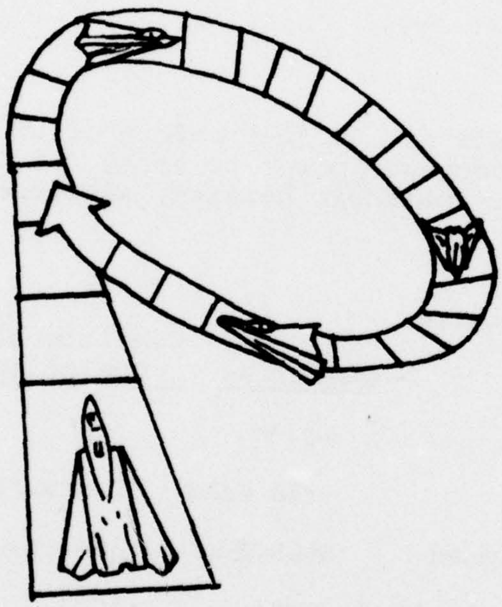


Figure 6. "S-2" Pattern

2. Basic Supporting Maneuvers

a)	Entry	Straight and Level Basic Transitions
b)	Maneuver	One-half SRT Turns Level Speed Changes and ½ SRT Climbs and Descents

3. Procedure

a) Three seconds prior to start 1) reduce power to

about 80%; 2) lower nose to about -3°; 3) roll into one-half SRT, bank 10% of speed

b) Adjust attitude and throttle to maintain 250 KIAS, 1,000 fpm descent

c) Check 30° turn at 20 seconds, adjust turn rate

d) Check 60° turn at 40 seconds, adjust turn rate

e) Three seconds or 100 feet before end of descent, increase power to 92%, raise nose to about +3°

f) Check 90° turn at 60 seconds

g) Adjust attitude and throttle to maintain 250 KIAS and 1,000 fpm ascent

h) Check 120° turn at 90 seconds, adjust turn rate

i) Check 150° turn at 100 seconds, adjust turn rate

j) Three seconds or 100 feet before top of ascent, reduce power to about 80% and lower nose to about -3°. Maintain turn

k) Check 180° turn at 120 seconds, adjust turn rate

l) Adjust attitude and throttle to maintain 250 KIAS and 1,000 fpm descent

m) Check 270° turn at 140 seconds, adjust turn rate

n) Check 240° turn at 160 seconds, adjust turn rate

o) Three seconds before end of descent, add power to about 92%, raise nose to about +3°, maintain turn rate

p) Check 270° turn at 180 seconds, adjust turn rate

q) Adjust attitude and power to maintain 200 KIAS and 1,000 fpm ascent

r) Check 300° turn at 200 seconds, adjust turn rate

s) Check 320° turn at 220 seconds, adjust turn rate

t) Three seconds or 100 feet before top of ascent, reduce power and lower nose, roll out of turn

u) Check 10,000 feet altitude, 250 KIAS

4. Performance Criteria

	Qualified	Conditionally Qualified	Unqualified
a) Turn Rate	±.25°/sec	±.5°/sec	>± .5°/sec
b) Airspeed	±10 KIAS	±20 KIAS	> ±20 KIAS
c) Vertical Speed	±100 fpm	±200 fpm	>±200 fpm
d) Transition Altitude	±100'	±200'	>±200'
e) Transition Heading	±2.5°	±5°	>±5°

5. Difficulty Variables

   a) Aircraft Weight

   b) Turbulence

   c) Aircraft Speed

   d) Direction of Turn

   e) Partial Panel

D. Vertical "S-3" Pattern

1. Description. The "S-3" pattern is similar to the "S-2" pattern except that the direction of turn is reversed after 180° of turn. The maneuver is typically entered at 250 KIAS at 10,000 feet. Figure 7. portrays the maneuver.

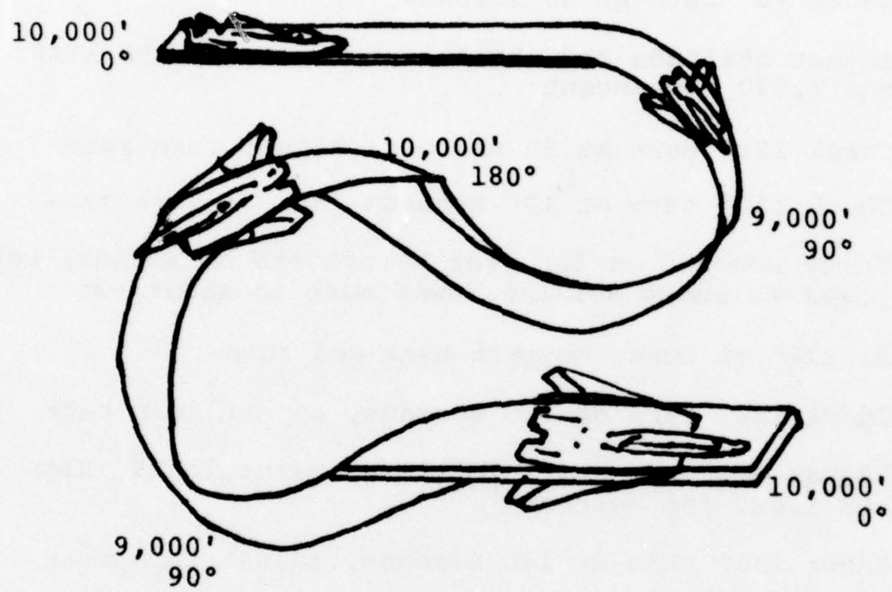


Figure 7. "S-3" Pattern

2. Basic Supporting Maneuvers

a)	Entry	Straight and Level Basic Transitions
b)	Maneuver	One-half SRT Turn Level Speed Changes and ½ SRT Climbs and Descents

3. Procedure

a) Three seconds prior to start 1) reduce power to about 80%; 2) lower nose to about -3°; 3) roll into one-half SRT, bank 10% of speed

b) Adjust attitude and throttle to maintain 250 KIAS, 1,000 fpm descent

c) Check 30° turn at 20 seconds, adjust turn rate

d) Check 60° turn at 40 seconds, adjust turn rate

e) Three seconds or 100 feet before end of descent, increase power to 92%, raise nose to about +3°

f) Check 90° turn at 60 seconds

g) Adjust attitude and throttle to maintain 250 KIAS and 1,000 fpm ascent

h) Check 120° turn at 90 seconds, adjust turn rate

i) Check 150° turn at 100 seconds, adjust turn rate

j) Three seconds or 100 feet before end of ascent, reduce power to about 80% and lower nose to about -3°

k) At 176° of turn, reverse bank and turn

l) Check 180° turn at 120 seconds, adjust turn rate

m) Adjust attitude and throttle to maintain 250 KIAS and 1,000 fpm descent

n) Check 150° turn at 140 seconds, adjust turn rate

o) Check 120° turn at 160 seconds, adjust turn rate

p) Three seconds before end of descent, add power to about 92%, raise nose to about +3°, maintain turn rate

q) Check 90° turn at 180 seconds, adjust turn rate

r) Adjust attitude and power to maintain 200 KIAS and 1,000 fpm ascent

s) Check 60° turn at 200 seconds, adjust turn rate

t) Check 30° turn at 200 seconds, adjust turn rate

u) Three seconds or 100 feet before top of ascent, reduce power and lower nose, roll out of turn

v) Check 10,000 feet altitude, 250 KIAS, original heading

4. Performance Criteria

	Qualified	Conditionally Qualified	Unqualified
a) Turn Rate	±.25°/sec	±.5°/sec	>±.5°/sec
b) Airspeed	±10 KIAS	±20 KIAS	±20 KIAS
c) Vertical Speed	±100 fpm	±200 fpm	>±200 fpm
d) Transition Altitude	±100'	±200'	>±200'
e) Transition Heading	±10°	±20°	>±20°

5. Difficulty Variables

a) Aircraft Weight

b) Turbulence

c) Aircraft Speed

d) Direction of Turn

e) Partial Panel

E. Penetration Pattern

1. Description. The penetration begins at the Initial Approach Fix and ends at the Final Approach Fix where the "approach" phase begins. There are four types of penetrations.

a) The "straight-in" penetration

b) The "off-set" penetration

c) The arcing penetration

d) The teardrop penetration

Regardless of the type of penetration, the TA-4J penetrates at 250 KIAS and a descent rate of 4,000-6,000 fpm. Figure 8. illustrates the penetrations.

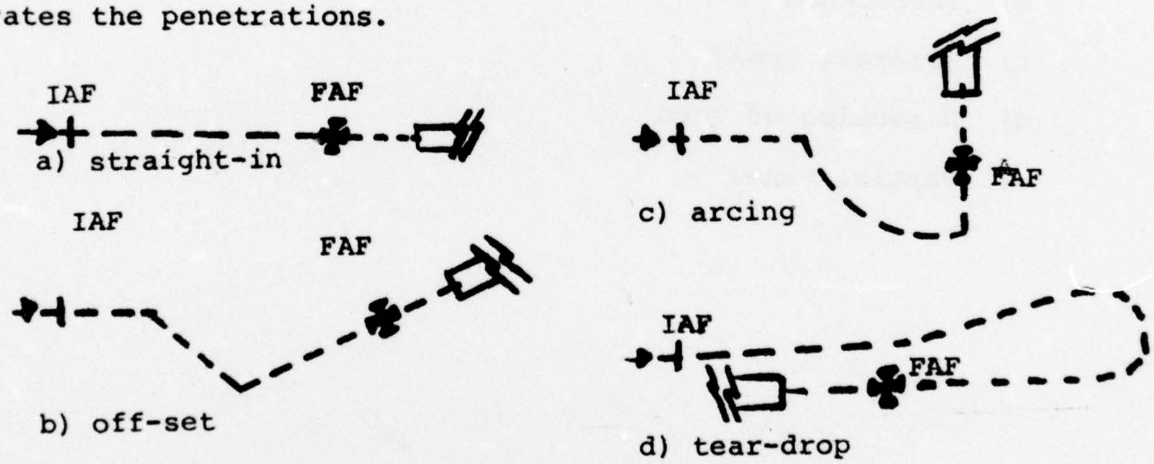


Figure 8. Penetrations

While different patterns such as those shown above are used for simulated penetration practice, the capability in modern trainers permits practice of all type of penetrations. The generic penetration for the TA-4J consists of a 250 KIAS 4,000-6,000 fpm descent to approach altitude. Transition to approach speed and configuration, 220 KIAS, gear and flaps down, 16 1/2 units AOA and straight and level should occur approximately two miles before FAF.

2. Basic Supporting Maneuvers

a)	Entry	Basic Transitions Straight and Level One-Half SRT Turns
b)	Maneuver	Constant Rate of Climb/Descent One-Half SRT Turns Turn Patterns

3. Procedure

a) Three seconds before starting descent, reduce power to 80%, begin 4,000-5,000 fpm descent. If above 250 KIAS, lower nose, extend speed brakes as speed reaches 250 KIAS

b) Hold heading

c) Maintain 250 KIAS and 4,000-6,000 fpm descent

d) If turn required, three seconds before turn, bank to 30° or less as required for off-set, arcing or tear-drop penetration

e) Maintain 250 KIAS and 4,000-6,000 fpm descent

f) If in turn, at three seconds or at 6° to go, roll out of bank

g) At 5,000 feet, reduce nose down pitch by one-half

h) At 4,500 feet, level nose, slow to 220 KIAS

i) Drop gear and flaps

j) Slow to 16 1/2 AOA, 4,000 feet, at approach heading

4. Performance Criteria

	Qualified	Conditionally Qualified	Unqualified
a) Airspeed	±10 KIAS	±20 KIAS	>±20 KIAS
b) Descent Rate	±250 fpm	±500 fpm	>±500 fpm
c) Heading	± 2.5°	± 5°	> ±5°
d) Turn Rate	±.25°/sec	±.5°/sec	>±.5°/sec
e) Bank angle	±5°	±5°	>±5°
f) Altitude (final)	±100'	±200'	>200'

5. Difficulty Variables

   a) Type of Penetration

   b) Aircraft Weight

   c) Turbulence

   d) Emergencies

II. CONFIDENCE MANEUVERS

A. Aileron Roll

1. Description. In an aileron roll, the aircraft is rolled 360 degrees about its longitudinal axis. The maneuver is entered from straight and level flight. The nose is raised and then the roll initiated. The aircraft should be wings level at the inverted position. Recovery should be nose low in a wings level attitude. Roll rate is constant. Figure 9. portrays the aileron roll. The TA-4J normally enters the aileron roll at 90% power and 300 KIAS.

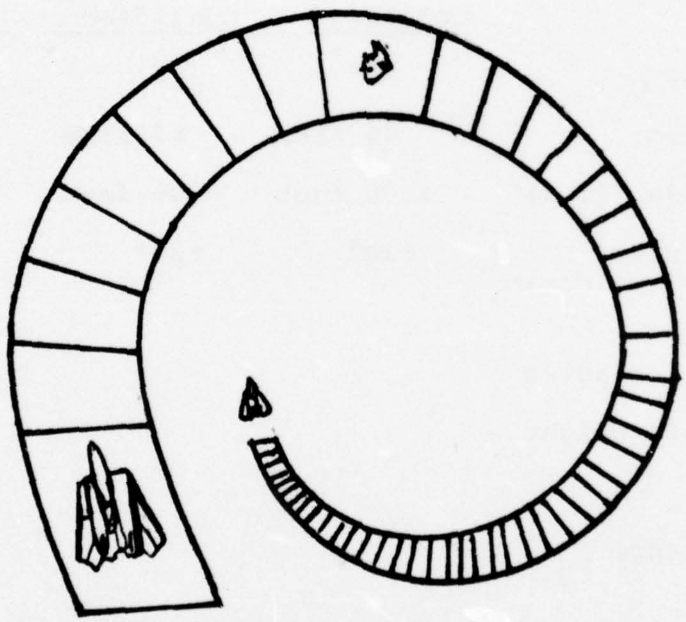


Figure 9. Aileron Roll

2. Basic Supporting Maneuvers

a) Entry	Straight and Level
b) Maneuver	Constant Angle of Bank

3. Procedure

   a) Smoothly raise nose 15 degrees above horizon

   b) Relax back pressure, enter roll

   c) Adjust roll rate so inverted, wings level, as nose passes through horizon

   d) Maintain heading and speed

   e) Adjust roll rate to recover nose low, wings level

   f) Stop roll, maintain altitude, heading and 300 KIAS

4. Performance Measures

	Qualified	Conditionally Qualified	Unqualified
a) Heading	±5°	±7°	>±7°
b) Airspeed	±5 KIAS	±7 KIAS	>±7 KIAS
c) Altitude (final)	±100 feet	±200 feet	>±200 feet
d) Procedures (roll points)	±10°	±20°	>±20°

5. Difficulty Variables

   a) Aircraft Weight

   b) Speed

   c) Turbulence

B. Wingover

1. Description. The wingover is a combination climbing and diving turn with 180° change in heading. A steep climbing turn is initiated. A 45° of heading change should have occurred at 45° pitch (maximum pitch). A 90° bank occurs at 90° of heading change. As the nose passes through the horizon, a gradual roll

out is started so that 45° nose down occurs at 135° of heading change. The recovery should be at the same altitude and speed as entry. Figure 10 illustrates the maneuver. It is normally performed twice in succession so that a return is made to the original heading.

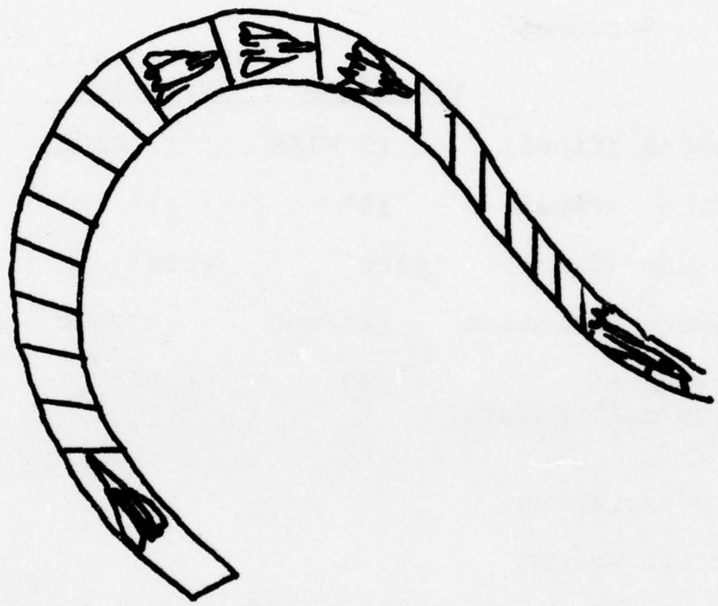


Figure 10. Wingover

2. Basic Supporting Maneuvers

a)	Entry	Straight and Level Basic Transitions
b)	Maneuver	Climb and Descent Constant Angle of Bank Turns

3. Procedure

a) Adjust power to about 92%, speed to 350 KIAS

b) Raise nose and roll into climbing turn

c) Check maximum pitch 45° and 45° heading change

d) Ease back pressure on stick, continue increasing bank

e) Check roll at 90° at 90° heading change

f) Start gradual rollout as nose passes through horizon

g) Check maximum nose down 45° at 135° heading change

h) Continue roll while pulling out to wings level at 180° heading change

4. Performance Measures

	Qualified	Conditionally Qualified	Unqualified
a) Airspeed (final)	±5 KIAS	±7 KIAS	>±7 KIAS
b) Heading (final)	±5°	±7°	>±7°
c) Altitude (final)	±100'	±200'	>±200'
d) Rollrate Variation	±2°/sec	±4°/sec	>±4°/sec
e) Procedures (pitch/roll points)	±5°	±10°	>±10°

5. Difficulty Variables

A) Aircraft Weight

b) Aircraft Speed

c) Turbulence

C. Barrel Roll

1. Description. The barrel roll is a combination climbing and diving maneuver accomplished by rolling the aircraft about a point 45° off the aircraft initial heading. A climbing roll is initiated such that 90^0 of heading change occurs as the aircraft passes through the horizon inverted. The nose of the aircraft should reach 45° above the horizon as 90° of roll is completed. The roll is continued so that nose low (45° below the horizon) is achieved when wings are 90° to horizon. Initiate rollout to

original altitude and heading. Figure 11 portrays the maneuver.

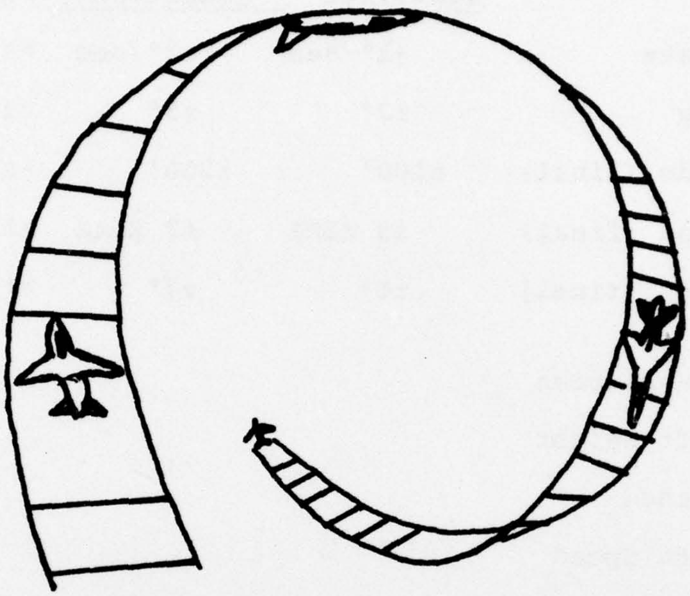


Figure 11. Barrel Roll

2. Basic Supporting Maneuvers

a)	Entry	Straight and Level Level Speed Changes
b)	Maneuver	Climbs and Dives Constant Angle of Bank Turns

3. Procedure

a) Establish 350 KIAS at 10,000 feet, 90-95% power

b) Raise nose and initiate roll with 2-3 g's

c) Check 45° nose up at 90° of roll

d) Check 90° heading change as nose passes through horizon (inverted), 210 KIAS

e) Roll out straight and level, 250 KIAS, 10,000 feet of altitude at original heading

4. Performance Measures

	Qualified	Conditionally Qualified	Unqualified
a) Roll Rate	±1°/sec	±.2°/sec	>±.2°/sec
b) Heading	±2°	±5°	>±5°
c) Altitude (final)	±100'	±200'	>±200'
d) Airspeed (final)	±5 KIAS	±7 KIAS	>±7 KIAS
e) Heading (final)	±5°	±7°	>±7°

5. Difficulty Variables

a) Aircraft Weight

b) Turbulence

c) Aircraft Speed

d) Roll Rate

D. Loop

1. Description. A loop is a 360° turn in the vertical plane. Heading is held constant. A combination sequence of constant 'g' to optimum AOA to constant 'g' is utilized. A constant rate of rotation about the lateral axis is maintained. Figure 12 portrays the loop maneuver.

2. Basic Supporting Maneuvers

a) Entry	Straight and Level Basic Transitions
b) Maneuver	Constant Rate Climbs and Descents Vertical "S-1" and "S-2"

3. Procedure

a) Establish MIL RPM and 450 KIAS at 15,000feet

b) Pull stick back and establish 4 g' acceleration

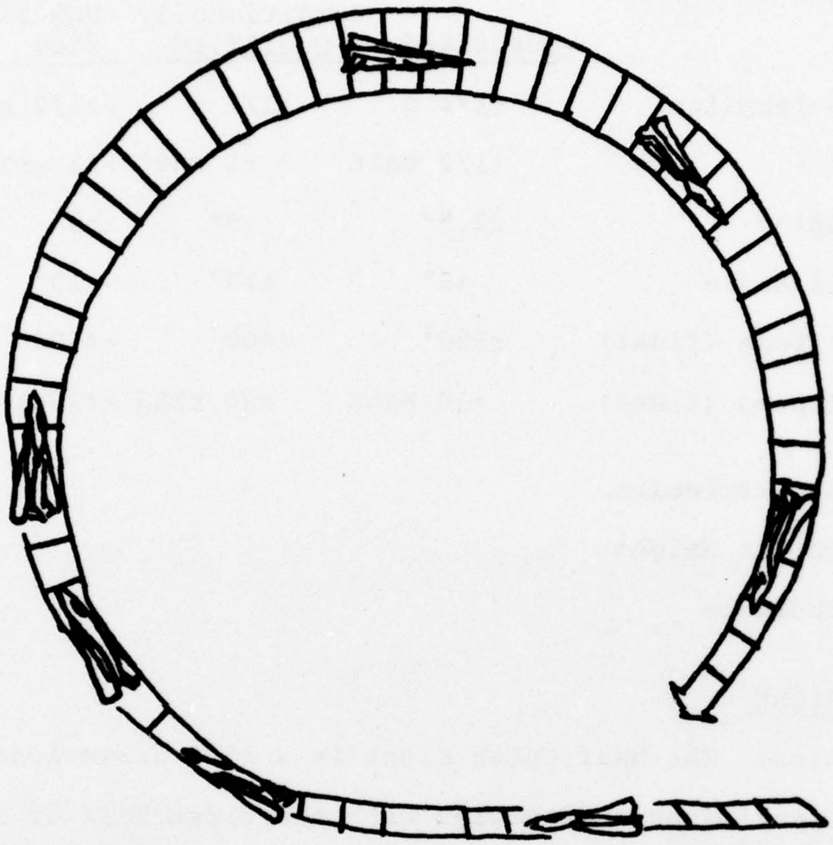


Figure 12. Loop

c) Maintain heading and wings level

d) Transition to 16 1/2 units AOA at near vertical when unable to maintain 4 g's

e) Maintain 16 1/2 units AOA over the top vertical until acceleration builds to 4 g's

f) Transition to 4 g flight

g) Maintain heading and wings level

h) At 10° nose down, ease stick forward to straight and level

i) Maintain original heading, speed, altitude

4. Performance Measures

		Qualified	Conditionally Qualified	Unqualified
a)	Acceleration	±1/4 g	±1/2 g	>±1/2 g
b)	AOA	±1/2 unit	±1 unit	>±1 unit
c)	Heading	±2.5°	±5°	>±5°
d)	Roll Angle	±5°	±10°	>±10°
e)	Altitude (final)	±200'	±400'	>±400
f)	Airspeed (final)	±10 KIAS	±20 KIAS	>±20KIAS

5. Difficulty Variables

a) Aircraft Weight

c) Turbulence

E. Half Cuban Eight

1. Description. The Half Cuban Eight is a 180° directional turn in the vertical plane. It begins with the first half of a loop followed by a rollout from the inverted dive position. It is begun the same as a loop. As the nose passes through the horizon inverted, the aircraft is flown into a 45° inverted dive. At this point, the aircraft is rolled wings level and a smooth pull out to level flight is achieved. The final heading is 180° from the entry heading at the same speed. Figure 13 illustrates the Half cuban Eight.

2. Basic Supporting Maneuvers

a) Entry — Straight and Level
Basic Transition

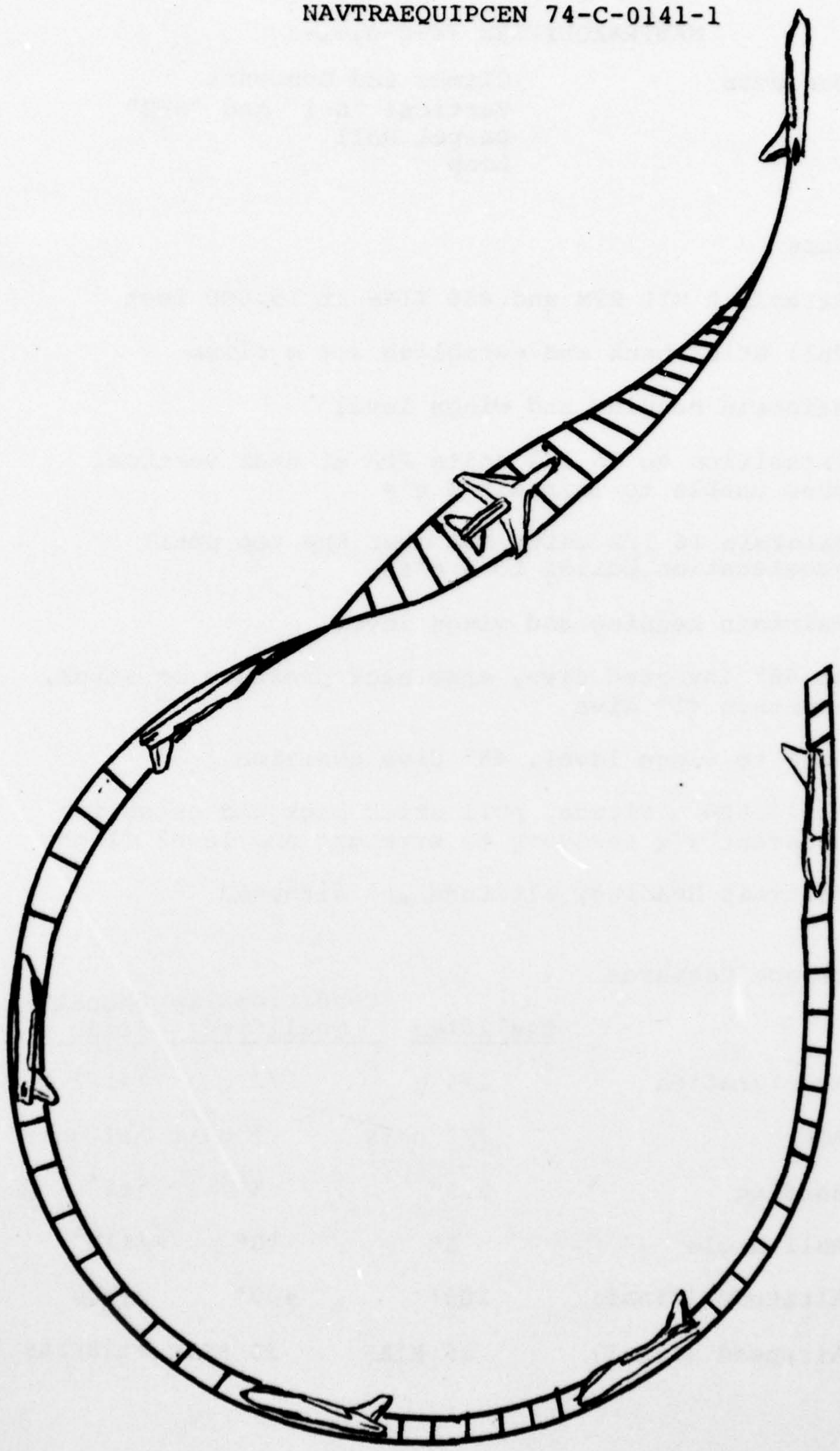


Figure 13. Half Cuban Eight

b) Maneuver — Climbs and Descents
Vertical "S-1" and "S-2"
Barrel Roll
Loop

3. Procedure

a) Establish MIL RPM and 450 KIAS at 15,000 feet

b) Pull stick back and establish a 4 g climb

c) Maintain heading and wings level

d) Transition to 16 1/2 units AOA at near vertical when unable to maintain 4 g's

e) Maintain 16 1/2 units AOA over the top until acceleration builds to 4 g's

f) Maintain heading and wings level

g) At 45° inverted dive, ease back pressure on stick, maintain 45° dive

h) Roll to wings level, 45° dive position

i) At 17,000 altitude, pull stick back and establish constant 4 g recovery to straight and level flight

j) Maintain heading, altitude and airspeed

4. Performance Measures

	Qualified	Conditionally Qualified	Unqualified
a) Acceleration	1/4 g	1/2 g	>±1/2 g
b) AOA	1/2 unit	1 unit	>±1 unit
c) Heading	2.5°	5°	>±5°
d) Roll Angle	5°	10°	>±10°
e) Altitude (final)	200'	400'	>±400
f) Airspeed (final)	10 KIAS	20 KIAS	>±20KIAS

5. Difficulty Variables

a) Aircraft Weight

b) Turbulence

F. Immelmann

1. Description. The Immelmann is a 180° turn in the vertical plane. Unlike the Half Cuban Eight, altitude is gained and speed lost. It consists of the first half of a loop, followed by a roll to level flight. Figure 14 illustrates the maneuver.

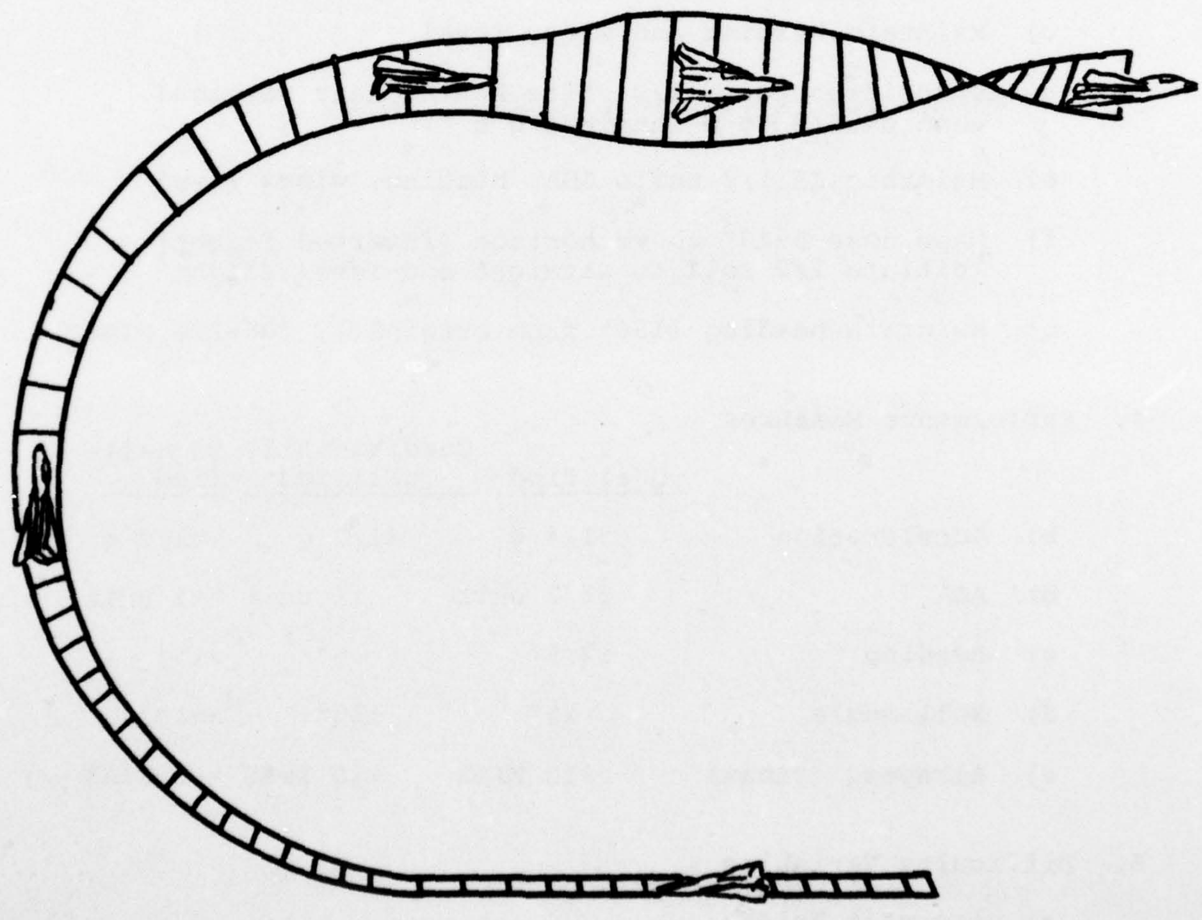


Figure 14. Immelmann

2. Basic Supporting Maneuvers

a)	Entry	Straight and Level Basic Transitions
b)	Maneuver	Constant Rate Climbs and Descents Vertical "S-1" and "S-2" Barrel Roll Loop

3. Procedure

a) Establish MIL RPM and 450 KIAS at 15,000 feet

b) Pull stick back and establish a 4 g climb

c) Maintain heading and wings level

d) Transition to 16 1/2 units AOA at near vertical when unable to maintain 4 g's

e) Maintain 16 1/2 units AOA, heading, wings level

f) When nose 5-10° above horizon (inverted flight), initiate 1/2 roll to straight and level flight

g) Maintain heading (180° from original), 200-220 KIAS

4. Performance Measures

		Qualified	Conditionally Qualified	Unqualified
a)	Acceleration	±1/4 g	±1/2 g	>±1/2 g
b)	AOA	±1/2 unit	±1 unit	>±1 unit
c)	Heading	±2.5°	±5°	>±5°
d)	Roll Angle	±5°	±10°	>±10°
e)	Airspeed (final)	±10 KIAS	±20 KIAS	>±20KIAS

5. Difficulty Variables

a) Aircraft Weight

b) Turbulence

G. Split-S

1. Description. The split-S is a 180° vertical turn with a loss of altitude. It consists of a half roll to the inverted position, followed by the last half of a loop. Most of the turn is accomplished in the initial part of the loop. Figure 15 portrays the maneuver.

2. Basic Supporting Maneuvers

a)	Entry	Straight and Level Basic Transitions
b)	Maneuver	Climbs and Descents Vertical "S-1" and "S-2" Barrel Roll Loop

3. Procedure

a) Establish 220 KAIS, 80% power at 20,000 feet

b) Raise nose 10-15° above horizon and roll inverted

c) Maintain heading

d) Pull stick back to establish 16 1/2 units AOA

e) Transition to constant 4 g and pull out to level flight

f) Maintain heading 180° from original

4. Performance Measures

		Qualified	Conditionally Qualified	Unqualified
a)	Acceleration	±1/4 g	±1/2 g	>±1/2 g
b)	AOA	±1/2 unit	±1 unit	>±1 unit
c)	Roll Angle	±5°	±10°	>±10°
d)	Heading (final)	±2.5°	±5°	>±5°

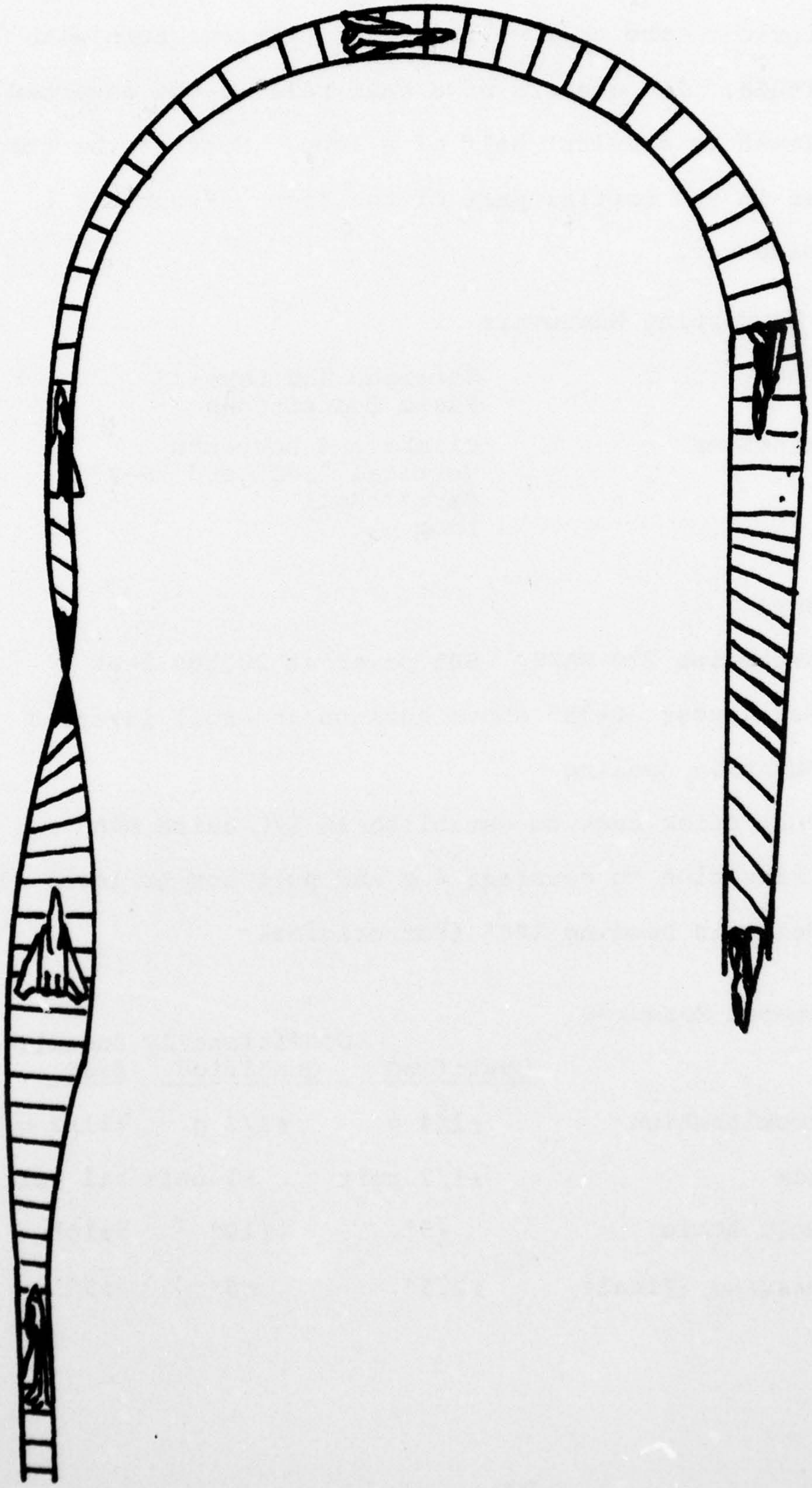


Figure 15. Split-S

5. Difficulty Variables

   a) Aircraft Weight

   b) Turbulence

H. Squirrel Cage

1. Description. The squirrel cage maneuver is a coordinated series of the overhead aerobatic maneuvers. It begins with a loop, proceeds through a Half Cuban Eight, and Immelmann and finally a split-S. Speed changes are required between maneuvers.

2. Basic Supporting Maneuvers

a) Entry	Straight and Level Basic Tranistions
b) Maneuver:	Loop Half-Cuban eight Immelmann Split-S

3. Procedure

   a) Establish MIL RPM and 450 KIAS at 15,000 feet

   b) Pull stick back and establish a 4 g climb

   c) Maintain heading and wings level

   d) Transition to 16 1/2 units AOA at near vertical when unable to maintain 4 g's

   e) Maintain 16 1/2 units AOA on the top until acceleration builds to 4 g's

   f) Maintain 4 g's, let speed build to 450 KIAS

   g) Ease stick forward to level out at 15,000', 450 KIAS

   h) Maintain heading, wings level

   i) Pull stick back, establish 4 g climb

   j) Transition to 16 1/2 units AOA as g's drop

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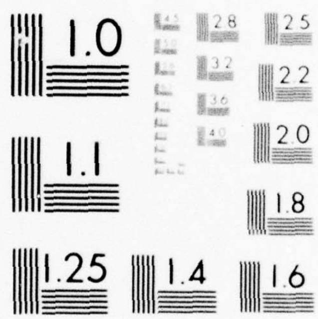

MICROCOPY RESOLUTION TEST CHART
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5. Difficulty Variables

   a) Aircraft Weight

   b) Turbulence

H. Squirrel Cage

1. Description. The squirrel cage maneuver is a coordinated series of the overhead aerobatic maneuvers. It begins with a loop, proceeds through a Half Cuban Eight, and Immelmann and finally a split-S. Speed changes are required between maneuvers.

2. Basic Supporting Maneuvers

a)	Entry	Straight and Level Basic Tranistions
b)	Maneuver.	Loop Half-Cuban eight Immelmann Split-S

3. Procedure

   a) Establish MIL RPM and 450 KIAS at 15,000 feet

   b) Pull stick back and establish a 4 g climb

   c) Maintain heading and wings level

   d) Transition to 16 1/2 units AOA at near vertical when unable to maintain 4 g's

   e) Maintain 16 1/2 units AOA on the top until acceleration builds to 4 g's

   f) Maintain 4 g's, let speed build to 450 KIAS

   g) Ease stick forward to level out at 15,000', 450 KIAS

   h) Maintain heading, wings level

   i) Pull stick back, establish 4 g climb

   j) Transition to 16 1/2 units AOA as g's drop

k) Maintain 16 1/2 units AOA over the top, transitioning to 4 g's as acceleration builds

l) Maintain heading and wings level

m) At 45° of dive, ease back pressure on stick, maintain 45° dive

n) Roll to wings level, 45° dive

o) At 17,000 feet altitude, pull stick back, establish constant 4 g recovery to straight and level flight, 450 KIAS at 15,000 feet at original heading

p) Pull stick back and initiate 4 g climb

q) Maintain heading and wings level

r) Transition to 16 1/2 units AOA at near vertical when unable to maintain 4 g's

s) Maintain 16 1/2 units AOA, heading, wings level

t) When nose 5-10° above horizon (inverted flight), initiate 1/2 roll to straight and level flight

u) Maintain heading (180° from entry heading)

v) Reduce power to 80%, maintain 220 KIAS, establish altitude 18,000 feet

w) Raise nose 10-15° above horizon and roll inverted

x) Maintain heading, wings level inverted

y) Pull stick back, establish 16 1/2 units AOA

z) Transition to constant 4 g and pull out to level flight.

4. Performance Measures

	Qualified	Conditionally Qualified	Unqualified
a) Acceleration	±1/4 g	±1/2 g	>±1/2 g
b) AOA	±1/2 unit	±1 unit	>±1 unit
c) Roll Angle	±5°	±10°	>±10°
d) Heading	±2.5°	±5°	>±5°

e) Airspeed	±10 KIAS	±20 KIAS	>±20 KIAS
f) Altitude	±200'	±400'	>±400'

5. Difficulty Variables

   a) Aircraft Weight

   b) Turbulence

III. OTHER MANEUVERS

A. Approach to Stall

1. Description. Approaches to stalls are flown in both clean and dirty configurations. The clean approach to stall is flown through both normal and accelerated stall onset. The dirty approach to stall is flown with speed brakes, gear and flaps extended. Accelerated or progressive stalls in the dirty configurations are not flown in the TA-4J.

2. Basic Supporting Maneuvers

a) Entry	Straight and Level Level Speed Changes
b) Maneuver	Climb and Descents Straight and Level

3. Procedure

   a) Clean approach:

      1) Establish heading, 80% power at 15,000 feet

      2) Raise nose 10-15 degrees above horizon

      3) Hold attitude and heading

      4) When buffet becomes heavy, add MIL power, lower nose below horizon, establish AOA 16 1/2 units

      5) Maintain heading and wings level

      6) At 160-170 KIAS, apply positive stick back pressure

      7) Maintain attitude and heading through buffet and slat opening

      8) At heavy buffet, establish 16 1/2 units AOA

      9) Establish straight and level flight

b) Dirty approach:

1) Establish heading, 80% power at 15,000 feet, speed brakes out, gear and flaps extended

2) Raise nose 10-15 degrees above horizon

3) Fly well into buffet region, maintain heading and altitude

4) When approaching stall, lower nose, add MIL power, retract speed brakes

5) Establish 16 1/2 units AOA

6) Maintain heading and altitude

4. Performance Measures

	Qualified	Conditionally Qualified	Unqualified
a) Heading	±2.5°	±5°	>±5°
b) AOA	±1/2 unit	±1 unit	>±1 unit
c) Roll	±5°	±10°	>±10°
d) Stall Sensing (AOA)	±1/2 unit	±1 unit	>±1 unit
e) Loss Altitude	±500 feet	±1,000 feet	>±1,000 feet

5. Difficulty Variables

a) Aircraft Weight

b) Turbulence

c) Malfunctions

B. Unusual Attitude (TA-4J)

1. Description. Recovery from unusual vertical attitudes involve nose high/low airspeed flight. Recovery depends on nose position and airspeed. Three different recovery procedures are involved.

a) Nose high/low airspeed (I)
KIAS < 100 or nose 60°-90° high inverted

b) Nose high/low airspeed (II)
150 > KIAS > 100; aircraft not 60°-90° nose high inverted

c) Nose high/low airspeed (III)
KIAS > 150 (manuevering airspeed)

Figure 16 summarizes those conditions.

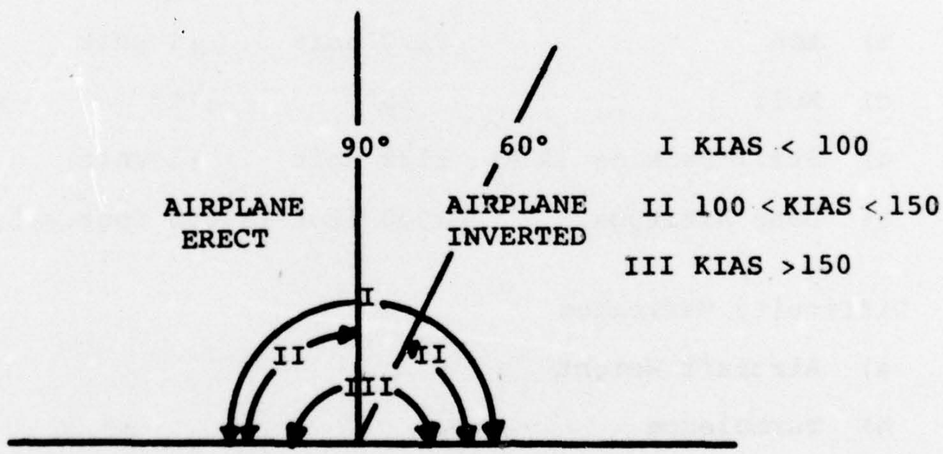


Figure 16. Unusual Attitude Recovery Regions

Condition I recovery involves neutralizing the controls and waiting for the ensuing gyration to end with the aircraft nose low and airspeed increasing to 170 KIAS. Normal recovery can then be accomplished by rolling erect and smoothly applying 16

1/2 units AOA to bring nose back to horizon. Recovery requires 3,000 to 5,000 feet.

Condition II recovery involves neutralizing controls and establishing 5 units AOA. As the nose passes below the horizon and speed increases to 170 KIAS, the aircraft is rolled erect and normal recovery accomplished.

Condition III recovery involves rolling inverted, applying positive g (16 1/2 units AOA) and as the nose passes below the horizon and speed increases to 170 KIAS, rolling erect and effecting normal recovery.

2. Basic Supporting Maneuver

a)	Entry	Not applicable
b)	Maneuver	Basic Transitions Climbs and Descents Turn Patterns Vertical "S-1" and "S-2" Confidence Maneuvers

3. Procedures

a) Condition I (aircraft nose high, erect or inverted, KIAS < 100)

1) Advance power to MRT

2) Neutralize controls

3) Check speed brakes in

4) Check altitude (if less than 5,000 feet, eject)

5) WAIT (aircraft may undergo falling leaf or rolling gyrations losing 2,000 - 3,000 ft.)

6) When nose below horizon and KIAS $>$ 170, roll erect

7) Apply AOA $\leq$ 16 1/2 units to bring aircraft back to straight and level flight

b) Condition II (aircraft nose high but not 60°-90° high inverted), $100 < \text{KIAS} < 150$

1) Advance power to MRT

2) Check speed brakes in

3) Neutralize controls

4) Establish 5 units AOA

5) As nose drops below horizon and KIAS $>$ 170, roll aircraft erect

6) Apply AOA $\geq$ 16 1/2 units and bring aircraft back to straight and level flight

c) Condition III (aircraft nose high, KIAS $\geq$ 150)

1) Roll aircraft inverted

2) Apply AOA $\leq$ 16 1/2 units

3) When nose passes below horizon and KIAS $\geq$ 170, roll erect, apply AOA $\leq$ 16 1/2 units and bring aircraft back to straight and level

4. Performance Measures

		Qualified	Conditionally Qualified	Unqualified
a) AOA		±1/2 units	±1 unit	>±1 unit
b) Altitude Loss	I	±3,000'	±5,000'	>±5,000'
	II	±1,000'	±3,000'	>±3,000'
	III	±1,000'	±3,000'	>±3,000'

5. Difficulty Variables

   a) Aircraft Weight

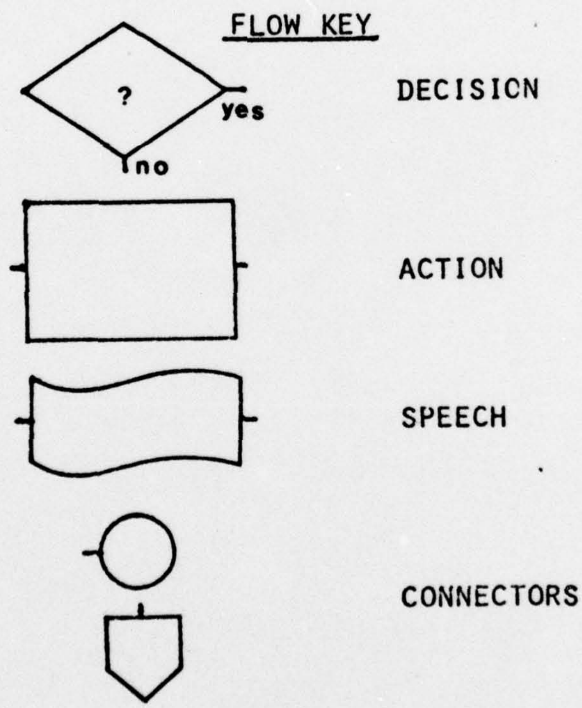
   b) Turbulence

   c) Pitch Attitude

   d) Emergency (especially partial panel)

APPENDIX B

FUNCTION FLOW DIAGRAM



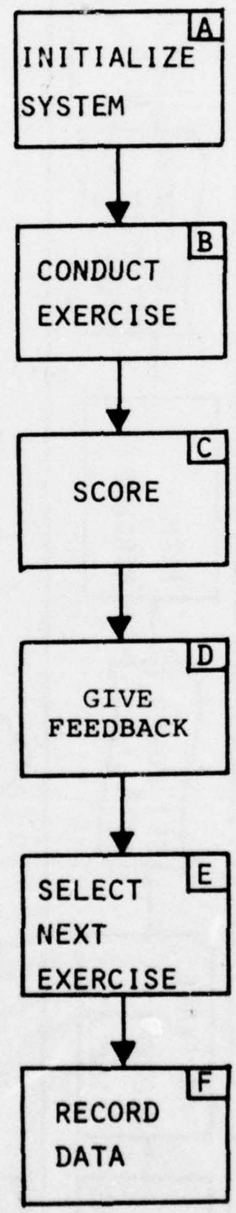


Figure 17. Basic training function flow.

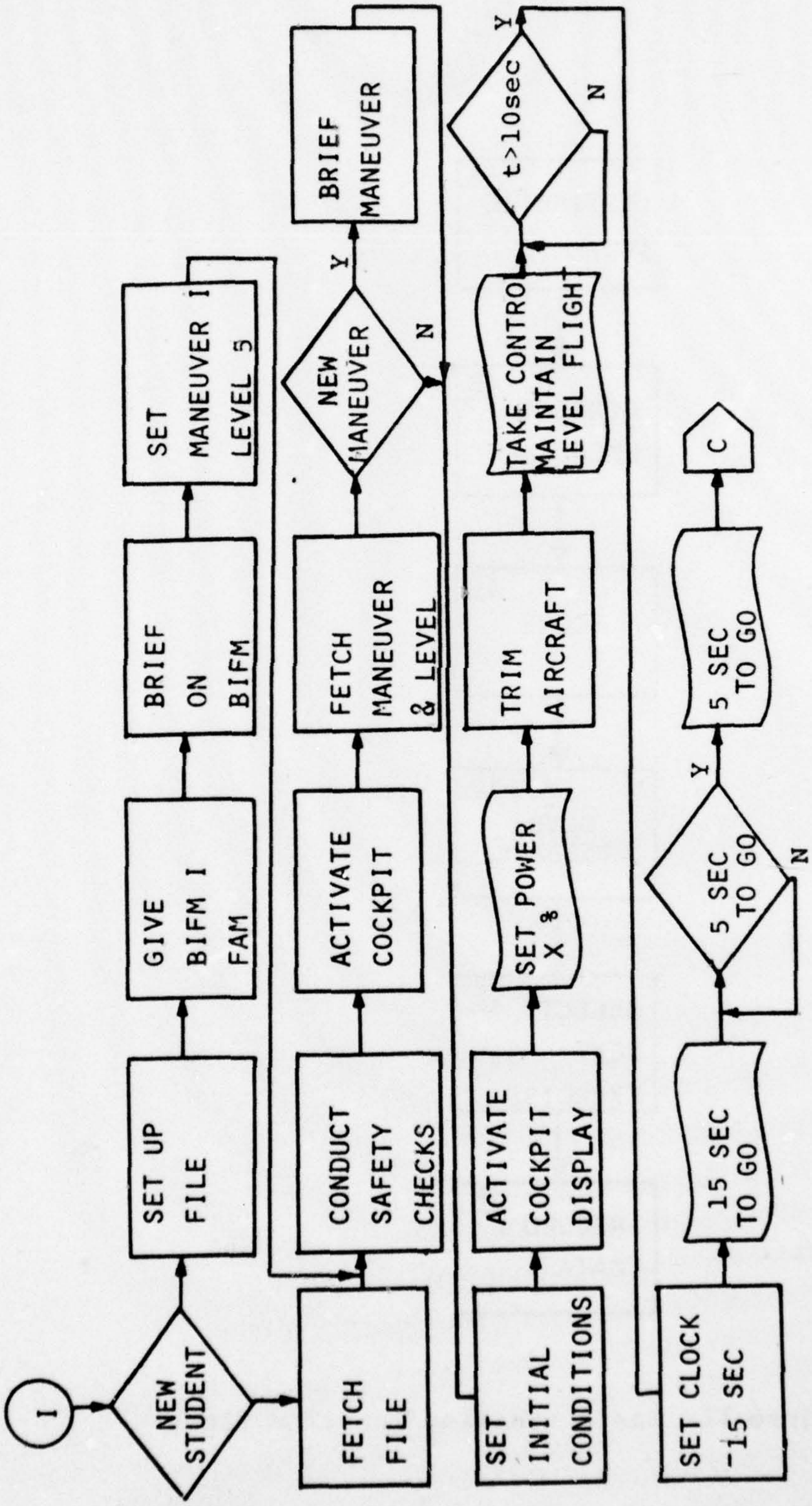


Figure 18. Initialize function flow.

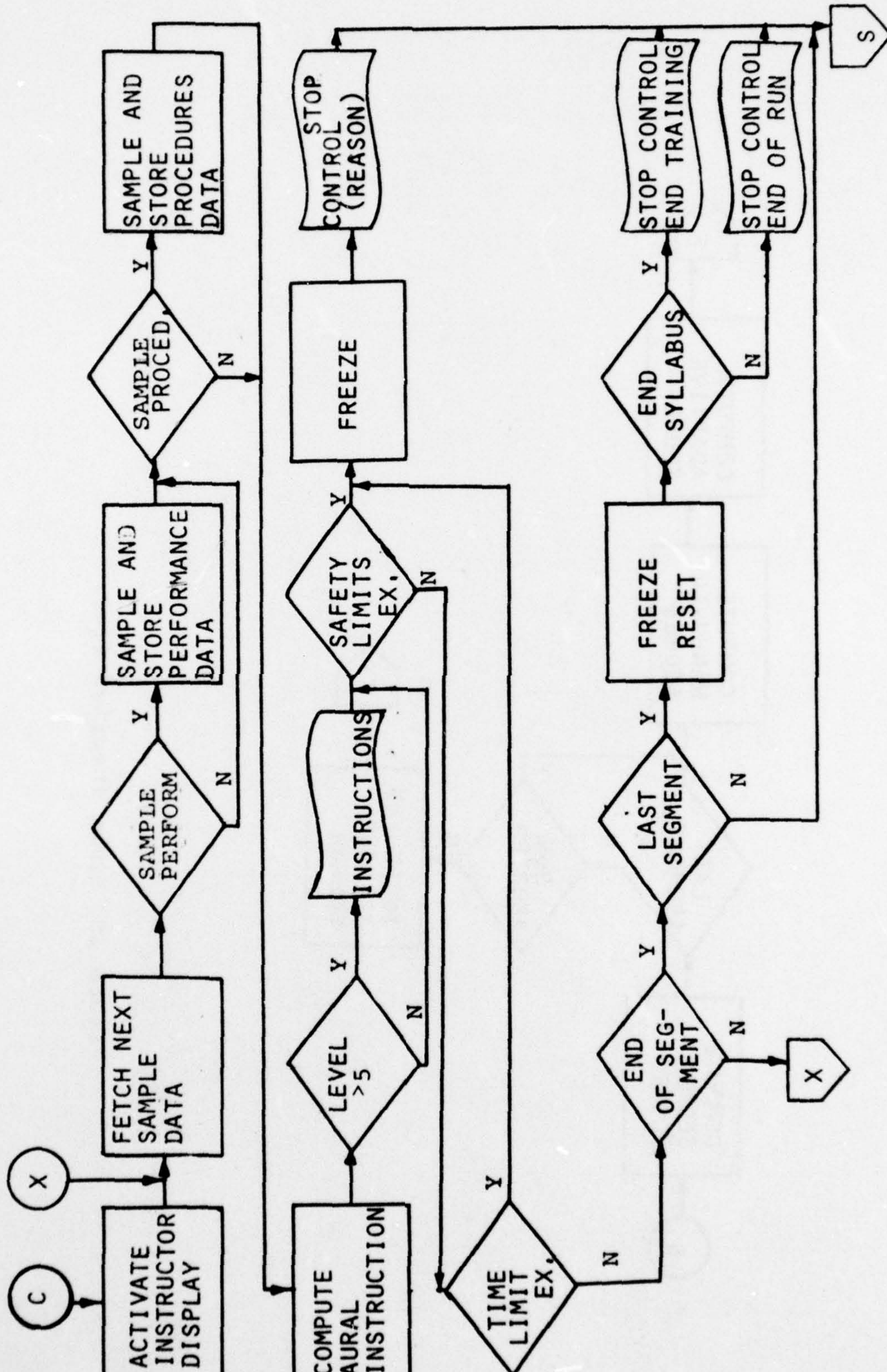


Figure 19. Conduct exercise function flow.

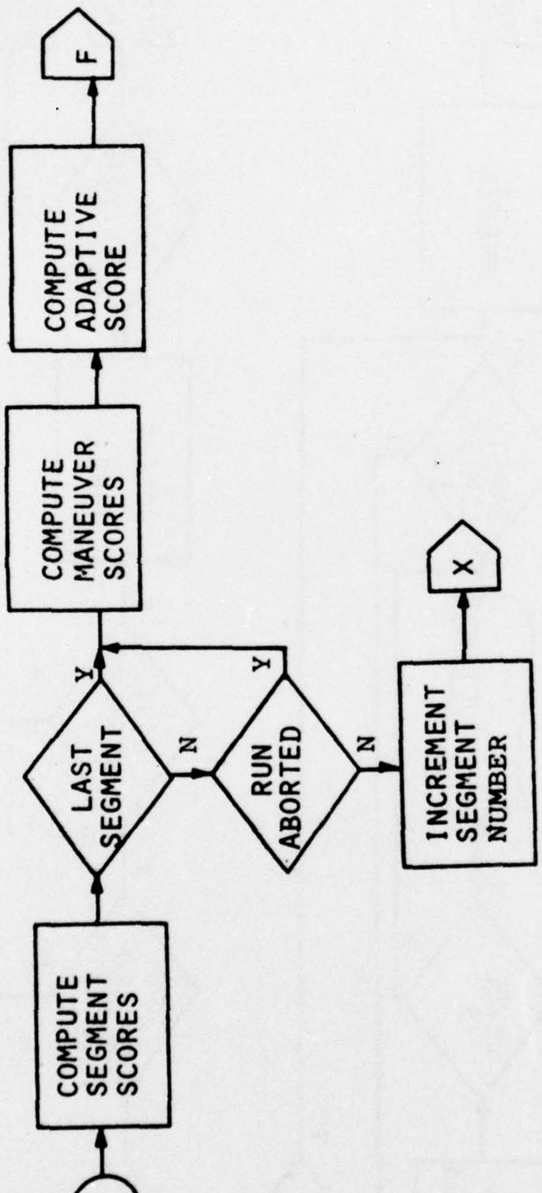


Figure 20. Score function flow.

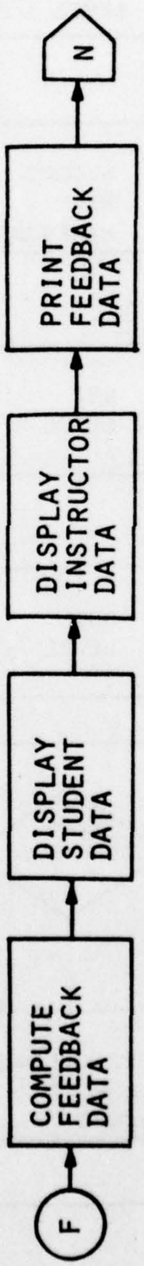


Figure 21. Give Feedback Function Flow

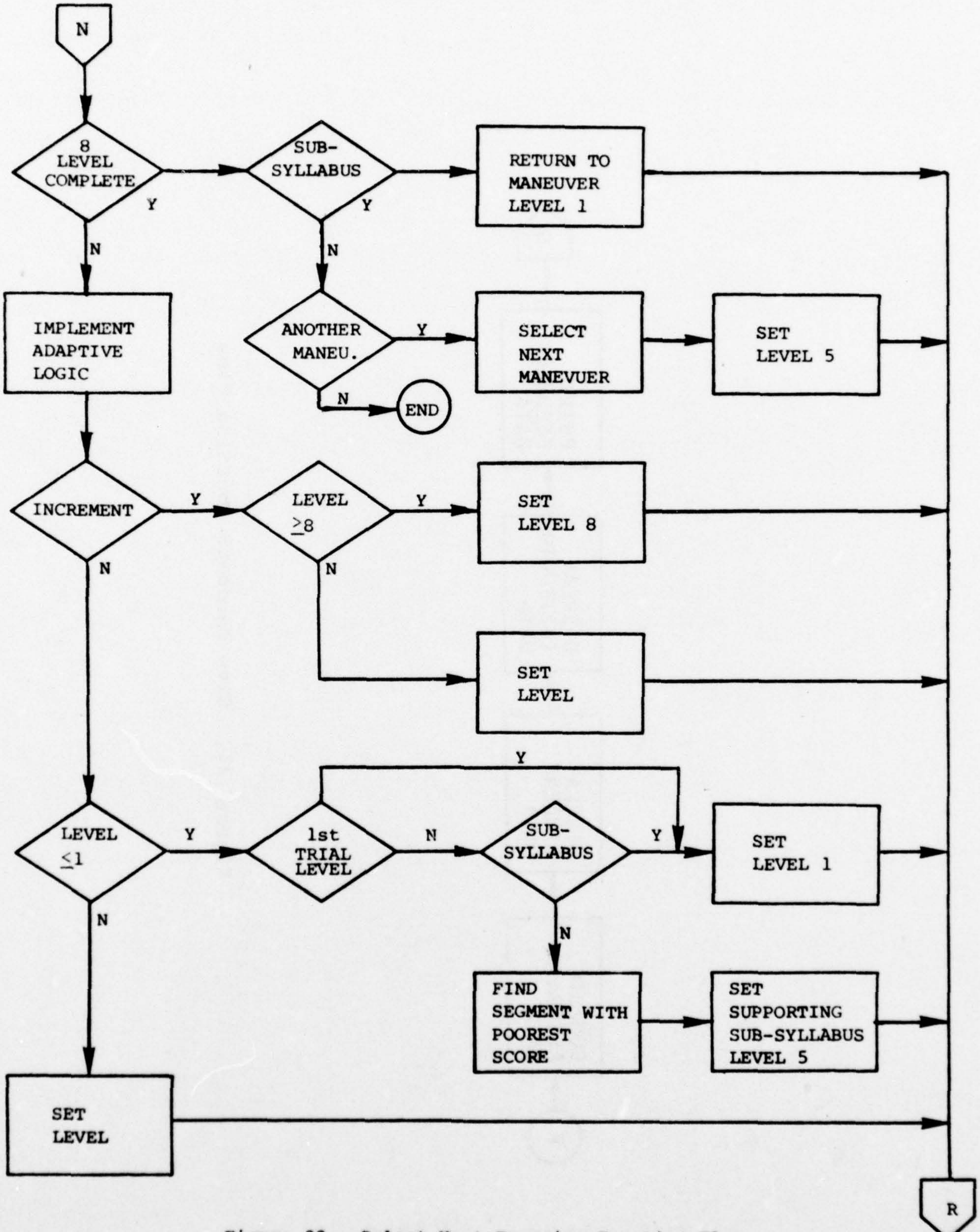


Figure 22. Select Next Exercise Function Flow

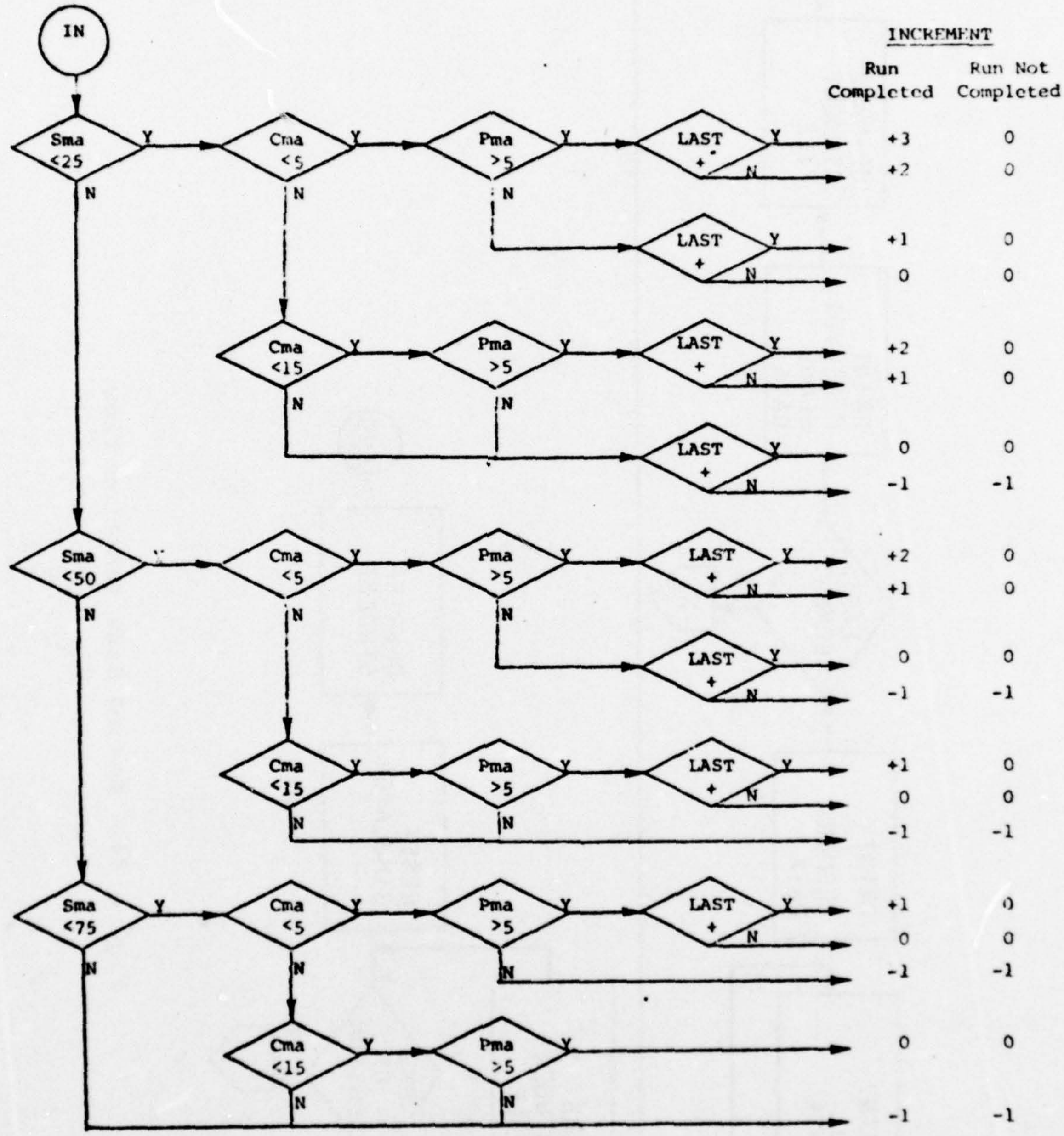


Figure 23. Adaptive logic.

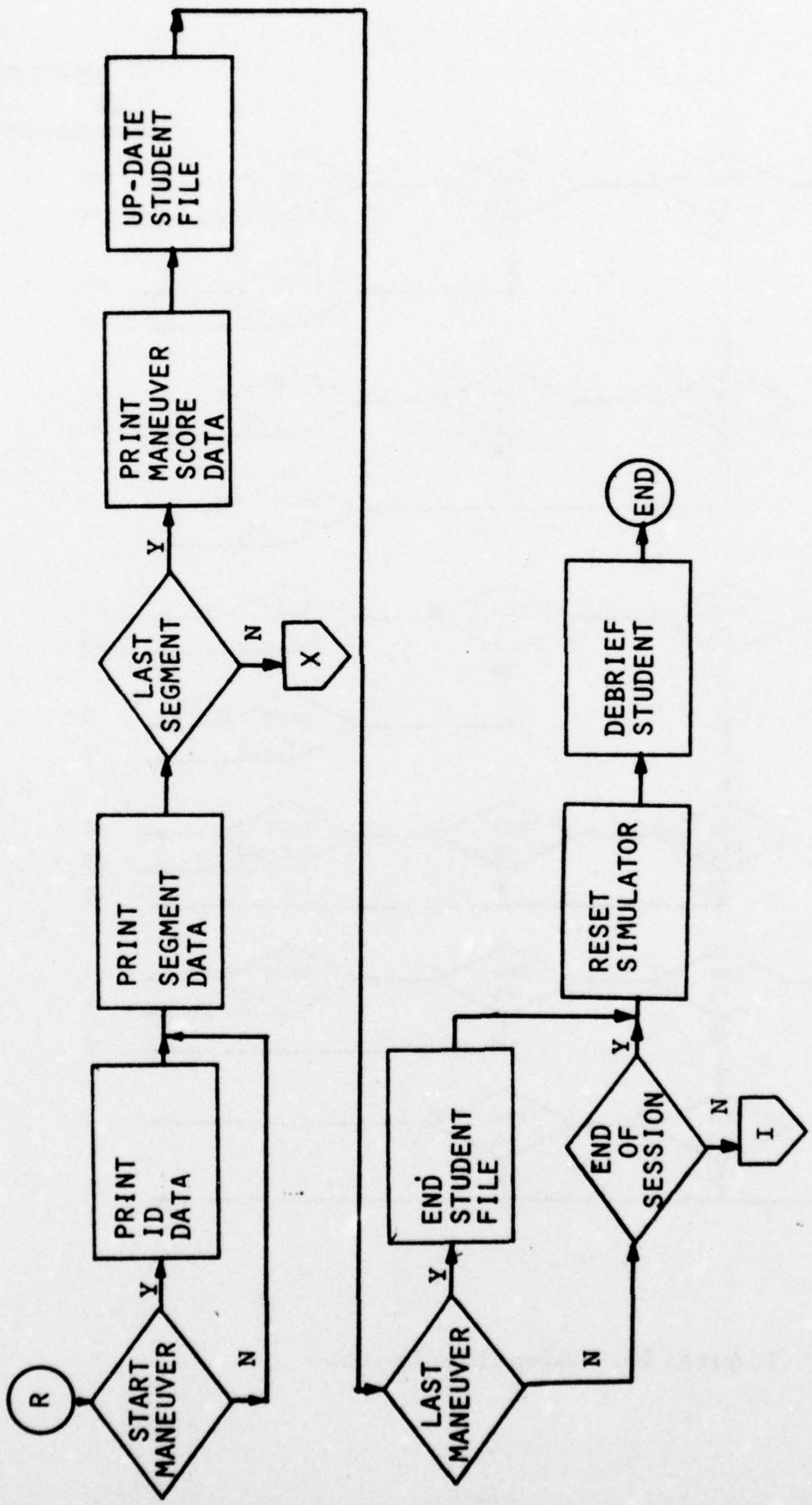


Figure 24. Record data function flow.

APPENDIX C

COMBINED BIFM AND AIR-TO-AIR SYLLABUS

The combined BIFM and Air-to-Air Syllabus which was actually implemented on the TRADEC consisted of two major sections. The first is the primary syllabus which included four precision, four confidence and three air-to-air maneuvers. The precision and confidence maneuvers were drawn from the set of the Advanced Jet Training Syllabus described in Appendix A. The air-to-air maneuvers were modifications of the attack tasks implemented in the GCI/CIC Air Attack study.[1]

The second section is the supporting sub-syllabus which consists of six basic instrument flight maneuvers selected in part from the Instrument Flight Maneuvers study.[2]

The primary syllabus consists of:

a. Precision Maneuvers
   (1) Turn Pattern
   (2) Vertical S-1
   (3) Vertical S-2
   (3) Vertical S-3
b. Confidence Maneuvers
   (1) Aileron Roll
   (2) Loop
   (3) Immelman
   (4) Split-S
c. Air-to-Air Maneuvers
   (1) Beam Attack
   (2) Forward Quarter Attack
   (3) Head-on Attack

---

[1]Charles, John P., Johnson, Robert M., and Swink, Jay R. <u>Automated Flight Training (AFT) GCI/CIC Air Attack</u>. Technical Report NAVTRAEQUIPCEN 72-C-0181-1, Naval Training Equipment Center, Orlando, Florida, 1973.

[2]Charles, J. P., Johnson, Robert M., and Swink, Jay R. <u>Automated Flight Training (AFT) Instrument Flight Maneuvers</u>. Technical Report NAVTRAEQUIPCEN 71-C-0205-1, Naval Training Equipment Center, Orlando, Florida, February 1973.

The sub-syllabus contains the following supporting maneuvers:

(1) Straight and Level Flight
(2) Climbs and Dives (Speed Constant)
(3) Climbs and Dives (Rate Constant)
(4) Turns (Constant Bank Angle)
(5) Climbing and Diving Turns (Rate Constant)
(6) Inverted Flight

The syllabus is arranged so that the maneuvers support or provide part task training in segments of the precision, confidence and air-to-air maneuvers. Each maneuver segment has a support maneuver which can be utilized for further training if the student is experiencing difficulty in completing that particular segment of the maneuver.

Since none of the "students" for the demonstration had recently, if ever, completed the Navy Basic Jet Training syllabus and were not familiar with the TRADEC cockpit and F-4 "vehicle", a brief familiarization period was also provided to insure that the student could operate the TRADEC cockpit and perform the following basic flight tasks:

(1) trim the aircraft
(2) fly straight and level
(3) make level speed changes
(4) elemetary level turns

To accomplish this, the familiarization exercise illustrated in table 6 was conducted.

TABLE 6. TRADEC FAMILIARIZATION EXERCISE

(1) Cockpit Checkout (by instructor)
- a. throttles
- b. speedbrake
- c. trim
- d. motion safety switch
- e. restraint devices
- f. E & S display
- g. communications
- h. instruments
  - basic flight
  - engine
  - AOA and G

(2) Basic Flight (30 second trials)
- a. straight and level
- b. trim in all axis
- c. basic speed changes
- d. turns (constant angle and standard rate)

Table 7 outlines the basic syllabus and initial conditions in detail. The difficulty factors employed are aircraft weight (or CG) and atmospheric turbulence. These difficulty factors which are labeled C/T in the table represent the following conditions:

Aircraft Weight (C)

Level 0	2,400 lbs. internal fuel
Level 1	Full internal fuel plus center tank

Atmospheric Turbulence (T)

Level 0	No turbulence
Level 1	Light turbulence

Initial conditions are expressed in the following units:

Ψ_I, Ψ_A, γ_T, ϕ	degrees
h_I	feet
V_I	KIAS
PWR	% engine RPM
R_T	NM
$\dot{h}$	feet per minute
$\dot{\psi}$	degrees per second

Table 8 summarizes the maneuver segments in similar detail. It lists the segment name, the start/stop conditions for the particular segment and the supporting sub-syllabus for that segment.

Table 9 lists the data collection requirements. Segment 1, which is common to all maneuvers in the primary syllabus and supporting sub-syllabus, is listed only once and appears at the beginning of the table. The parameters that make up the system and control scores are listed on the left side of the table while the procedure score criteria are shown on the right side. The symbols expressing the measures used in obtaining the system/control scores are:

e elapsed

s standard deviation

r root mean square

Both system scores and control scores involve the sampling and averaging of data throughout the segment with the exception of the first segment. The data are sampled at specified rates (Table 10) and stored for processing at the end of each segment. Most of the data are transformed using a root-mean-square algorithm; i.e.,

$$\sqrt{\frac{\Sigma X^2}{N}}$$

"X" is the sampled value and "N" is the number of such samples. Most of the data to be collected are error data. Thus, the transformation approaches the variance measure as the average error

decreases, and they become identical when the error is symmetrically distributed about the assigned value.

Three scores are computed for each segment or each maneuver. They are identified as the:

(1) system score

(2) control score

(3) procedures score

Although they are clearly interrelated, three different aspects of instrument proficiency are being sampled. The system score is concerned with overall system performance in terms of the governing parameters of the maneuver. The parameters typically sampled are heading, airspeed, bank, pitch, rates, or in general those parameters that establish the location and motion of the vehicle in space relative to the maneuver requirement. The system score is concerned with system performance and therefore operational criteria apply.

The control score samples the pilot's performance in terms of control inputs to the vehicle. The parameters typically sampled are stick and throttle displacement, slip, and time. The score aims at measuring the quality of the pilot's control input to the vehicle.

The procedures score summarizes the pilot's knowledge of the maneuver. Two facets are sampled. The first establishes if the pilot knows what the maneuver requirements are; the second checks to see if the pilot is performing the maneuver as taught in terms of anticipating or lead and in estimating control input needs.

The computation algorithm for the scores follows:

<u>SYSTEM SCORE, Sma</u>

$$Sma = \frac{\sum_{2}^{N} Wns\ Ssn}{N-1}$$

Where:
Sma = System score for maneuver a
Ssn = System score for segment n
Wns = Weight of segment system score n
N = Number of segments

Segment Score, Ss_n

$$Ssn = \frac{\sum_{1}^{K} Wsk\ Psk}{K}$$

Where:
Psk = System score for parameter k
Wsk = Weight of parameter score k
K = Number of parameters

CONTROL SCORE, Cma

$$Cma = \frac{\sum_{2}^{N} Wnc\ Csn}{N-1}$$

Where:
Cma = Control score for maneuver a
Csn = Control score for segment n
Wnc = Weight of segment control score n
N = Number of segments

Segment Score, Csn

$$Csn = \frac{\sum_{1}^{K} Wck\ Pck}{K}$$

Where:
Pck = Control score for parameter k
Wck = Weight of parameter score k
K number of parameters

PROCEDURES SCORE (Ps_1)

The procedures score for segment one is common to all maneuvers. The score establishes that the student is at the correct position for entering the maneuver. The score is called the Gate Score and is computed at minus five seconds to the hour (five seconds before the maneuver should begin). The score has a value of 1 or 0 as follows:

GATE SCORE (Segment One)

$Ps_1 = 1$ if $h_e \pm 200$ feet

$V_e \pm 20$ knots

$\psi_e \pm 10$ degrees

$\dot{h} \pm 200$ feet per minute

$\dot{\psi} \pm .5$ degrees per second

$\phi \pm 50$

$Ps_1 = 0$ otherwise

The procedures score for segment two samples the entry procedures as well as detecting initiation of the maneuver. The entry parameters are sampled at zero time and also at + 5 seconds. The zero sample detects proper lead or anticipation for the maneuver. The + 5 second sample detects last possible maneuver entry. If the student has not initiated the maneuver by this time, the trial is reinitialized. This score (at + 5 sec) is used only to freeze the simulation if 0.

ENTRY SCORE (Segment two)

Ps_2 = 1 if entry conditions are met
= 0 otherwise

The entry conditions along with the procedures scores for other segments are identified in Table 9. The maneuver procedure score Mp is a weighted sum of the segment scores. The computation is as follows:

Ps_a = 1 if all Ps_n are 1 0 otherwise	Ps_a = Procedures score for Maneuver a
Ps_n = 1 if all criteria met 0 otherwise*	Ps_n = Procedures score for Segment n

* Note: Ps_n = 1 for segments in which procedures not scored

The parameter weighting factor utilized in the system/control score computations are listed in Table 11.

TABLE 7. SYLLABUS

TURN PATTERN	C/T	Ψ_I	h_I	V_I	PWR	INITIAL
Level 1	00	360	20	300	83	Right
Level 2	01	180	20	300	83	Left
Level 3	00	090	5	200	82	Right
Level 4	01	270	5	200	82	Left
Level 5	10	360	20	300	85	Right
Level 6	11	180	20	300	85	Left
Level 7	10	090	5	200	84	Right
Level 8	11	270	5	200	84	Left
VERTICAL S-1	**C/T**	**Ψ_I**	**h_I**	**V_I**	**PWR**	**INITIAL**
Level 1	00	360	20	300	83	Climb
Level 2	01	180	20	300	83	Dive
Level 3	00	090	5	200	82	Climb
Level 4	01	270	5	200	82	Dive
Level 5	10	360	20	300	85	Climb
Level 6	11	180	20	300	85	Dive
Level 7	10	090	5	200	84	Climb
Level 8	11	270	5	200	84	Dive
VERTICAL S-2	**C/T**	**Ψ_I**	**h_I**	**V_I**	**PWR**	**INITIAL**
Level 1	00	360	20	300	83	Climb Right
Level 2	01	180	20	300	83	Dive Right
Level 3	00	090	5	200	82	Climb Left
Level 4	01	270	5	200	82	Dive Left
Level 5	10	360	20	300	85	Climb Right
Level 6	11	180	20	300	85	Dive Right
Level 7	10	090	5	200	84	Climb Left
Level 8	11	270	5	200	84	Dive Left

TABLE 7. SYLLABUS (cont.)

VERTICAL S-3	C/T	Ψ_I	h_I	V_I	PWR	INITIAL
Level 1	00	360	20	300	83	Climb Right
Level 2	01	180	20	300	83	Dive Right
Level 3	00	090	5	200	82	Climb Left
Level 4	01	270	5	200	82	Dive Left
Level 5	10	360	20	300	85	Climb Right
Level 6	11	180	20	300	85	Dive Right
Level 7	10	090	5	200	84	Climb Left
Level 8	11	270	5	200	84	Dive Left

AILERON ROLL	C/T	Ψ_I	h_I	V_I	PWR	INITIAL
Level 1	00	360	15	300	82	Roll Right
Level 2	01	180	15	300	82	Roll Right
Level 3	00	090	15	300	82	Roll Left
Level 4	01	270	15	300	82	Roll Left
Level 5	10	360	15	300	84	Roll Right
Level 6	11	180	15	300	84	Roll Right
Level 7	10	090	15	300	84	Roll Left
Level 8	11	270	15	300	84	Roll Left

LOOP	C/T	Ψ_I	h_I	V_I	PWR
Level 1	00	360	15	500	89
Level 2	00	180	15	500	89
Level 3	00	090	15	500	89
Level 4	00	270	15	500	89
Level 5	10	360	15	500	91
Level 6	10	180	15	500	91
Level 7	11	090	15	500	91
Level 8	11	270	15	500	91

TABLE 7. SYLLABUS (cont.)

IMMELMAN	C/T	Ψ_I	h_I	V_I	PWR	ROLL OUT
Level 1	00	360	15	500	89	Left
Level 2	00	180	15	500	89	Right
Level 3	00	090	15	500	89	Left
Level 4	00	270	15	500	89	Right
Level 5	10	360	15	500	91	Left
Level 6	10	180	15	500	91	Right
Level 7	11	090	15	500	91	Left
Level 8	11	270	15	500	91	Right

SPLIT-S	C/T	Ψ_I	h_I	V_I	PWR	INITIAL
Level 1	00	360	20	220	82	Roll Left
Level 2	00	180	20	220	82	Roll Right
Level 3	00	090	20	220	82	Roll Left
Level 4	00	270	20	220	82	Roll Right
Level 5	10	360	20	220	82	Roll Left
Level 6	10	180	20	220	82	Roll Right
Level 7	11	090	20	220	82	Roll Left
Level 8	11	270	20	220	82	Roll Right

BEAM ATTACK	C/T	Ψ_I	h_I	V_I	PWR	Ψ_A	γ_T	R_T
Level 1	00	300	15	500	89	270	-40	20
Level 2	01	240	15	500	89	270	-40	20
Level 3	00	120	15	500	89	090	40	20
Level 4	01	060	15	500	89	090	40	20
Level 5	10	300	15	500	91	270	-40	20
Level 6	11	240	15	500	91	270	-40	20
Level 7	10	120	15	500	91	090	40	20
Level 8	11	060	15	500	91	090	40	20

TABLE 7. SYLLABUS (cont.)

FORWARD QUARTER ATTACK	C/T	Ψ_I	h_I	V_I	PWR	Ψ_A	γ_T	R_T
Level 1	00	240	15	500	89	210	5	20
Level 2	01	180	15	500	89	210	5	20
Level 3	00	180	15	500	91	150	-5	20
Level 4	01	120	15	500	91	150	-5	20
Level 5	10	240	15	500	89	210	5	20
Level 6	11	180	15	500	89	210	5	20
Level 7	10	180	15	500	91	150	-5	20
Level 8	11	120	15	500	91	150	-5	20

HEAD-ON ATTACK	C/T	Ψ_I	h_I	V_I	PWR	Ψ_A	γ_T	R_T
Level 1	00	210	15	500	89	180	22	20
Level 2	01	150	15	500	89	180	22	20
Level 3	00	210	15	500	91	180	-22	20
Level 4	01	150	15	500	91	180	-22	20
Level 5	10	210	15	500	89	180	22	20
Level 6	11	150	15	500	89	180	22	20
Level 7	10	210	15	500	91	180	-22	20
Level 8	11	150	15	500	91	180	-22	20

STRAIGHT & LEVEL SUB.	C/T	Ψ_I	h_I	V_I	PWR
Level 1	00	360	20	300	83
Level 2	01	180	20	300	83
Level 3	00	090	5	200	82
Level 4	01	270	5	200	82
Level 5	10	360	20	300	85
Level 6	11	180	20	300	85
Level 7	10	090	5	200	84
Level 8	11	270	5	200	84

TABLE 7. SYLLABUS (cont.)

<u>CLIMB/DIVE SUB.</u> (Speed Constant-Climb/Dive 1000 feet)

	C/T	Ψ_I	h_I	V_I	PWR	INITIAL
Level 1	00	360	20	300	83	Climb
Level 2	01	180	20	300	83	Dive
Level 3	00	090	5	200	82	Climb
Level 4	01	270	5	200	82	Dive
Level 5	10	360	20	300	85	Climb
Level 6	11	180	20	300	85	Dive
Level 7	10	090	5	200	84	Climb
Level 8	11	270	5	200	84	Dive

<u>CLIMB/DIVE SUB.</u> (Rate Constant-Climb/Dive 1000 feet)

	C/T	Ψ_I	h_I	V_I	PWR	INITIAL	$\dot{h}$
Level 1	00	360	20	300	83	Climb	1000
Level 2	01	180	20	300	83	Dive	-1000
Level 3	00	090	5	200	82	Climb	1000
Level 4	01	270	5	200	82	Dive	-1000
Level 5	10	360	20	300	85	Climb	1000
Level 6	11	180	20	300	85	Dive	-1000
Level 7	10	090	5	200	84	Climb	1000
Level 8	11	270	5	200	84	Dive	-1000

<u>TURNS</u> (Constant Bank 90° Turn)

	C/T	Ψ_I	h_I	V_I	PWR	INITIAL	ϕ
Level 1	00	360	20	300	83	Right	30
Level 2	01	180	20	300	83	Left	30
Level 3	00	090	5	200	82	Right	45
Level 4	01	270	5	200	82	Left	45
Level 5	10	360	20	300	85	Right	45
Level 6	11	180	20	300	85	Right	60
Level 7	10	090	5	200	84	Right	60
Level 8	11	270	5	200	84	Left	60

TABLE 7. SYLLABUS (cont.)

CLIMBING/DIVING TURNS (Rate Constant-Climb/Dive 1000 feet; 90° Turn)

	C/T	Ψ_I	h_I	V_I	PWR	INITIAL	$\dot{h}$	$\dot{\Psi}$
Level 1	00	360	20	300	83	Climb Right	1000	1.5
Level 2	01	180	20	300	83	Dive Right	-1000	1.5
Level 3	00	090	5	200	82	Climb Left	1000	-1.5
Level 4	01	270	5	200	82	Dive Left	-1000	-1.5
Level 5	10	360	20	300	85	Climb Right	1000	1.5
Level 6	11	180	20	300	85	Dive Right	-1000	1.5
Level 7	10	090	5	200	84	Climb Left	1000	-1.5
Level 8	11	270	5	200	84	Dive Left	-1000	-1.5

<u>INVERTED FLIGHT</u> (30 Seconds)

	C/T	Ψ_I	h_I	V_I	PWR	INITIAL
Level 1	00	360	15	300	83	Roll Right
Level 2	01	180	15	300	83	Roll Right
Level 3	00	090	15	300	83	Roll Left
Level 4	01	270	15	300	83	Roll Left
Level 5	10	360	15	300	84	Roll Right
Level 6	11	180	15	300	84	Roll Right
Level 7	10	090	15	300	84	Roll Left
Level 8	11	270	15	300	84	Roll Left

TABLE 8. MANEUVER SEGMENTS

TURN PATTERN

	Segment	Start	Stop	Supporting
1.	Gate	-15 sec	0 sec	S&L
2.	Entry	0 sec	$\phi > 25^{\circ}$	CBT
3.	30° Bank	$\phi > 25^{\circ}$	$+54^{\circ}\Psi$	CBT
4.	Reversal	$+54^{\circ}\Psi$	$+54^{\circ}\Psi$	CBT
5.	30° Bank	$+54^{\circ}\Psi$	$+6^{\circ}\Psi$	CBT
6.	Reversal	$+6^{\circ}\Psi$	$+9^{\circ}\Psi$	CBT
7.	45° Bank	$+9^{\circ}\Psi$	$+81^{\circ}\Psi$	CBT
8.	Reversal	$+81^{\circ}\Psi$	$+81^{\circ}\Psi$	CBT
9.	45° Bank	$+81^{\circ}\Psi$	$+9^{\circ}\Psi$	CBT
10.	Reversal	$+9^{\circ}\Psi$	$+12^{\circ}\Psi$	CBT
11.	60° Bank	$+12^{\circ}\Psi$	$+168^{\circ}\Psi$	CBT
12.	Reversal	$+168^{\circ}\Psi$	$+168^{\circ}\Psi$	CBT
13.	60° Bank	$+168^{\circ}\Psi$	$+12^{\circ}\Psi$	CBT
14.	Transition S&L	$+12^{\circ}\Psi$	$0^{\circ}\Psi$	CBT

VERTICAL S-1

	Segment	Start	Stop	Supporting
1.	Gate	-15 sec	0 sec	S&L
2.	Entry	0 sec	$\dot{h} > 500$ ft/min	CDT
3.	First C/D	$\dot{h} > 500$ ft/min	$h_e > 900$ ft	CDT
4.	Reversal	$h_e > 900$ ft	$h_e < 900$ ft	CDT
5.	First D/C	$h_e < 900$ ft	$h_e < 100$ ft	CDT
6.	Reversal	$h_e < 100$ ft	$h_e > 100$ ft	CDT
7.	Second C/D	$h_e > 100$ ft	$h_e > 900$ ft	CDT
8.	Reversal	$h_e > 900$ ft	$h_e < 900$ ft	CDT
9.	Second D/C	$h_e < 900$ ft	$h_e < 100$ ft	CDT
10.	Transition S&L	$h_e < 100$ ft	10 sec	CDT

TABLE 8. MANEUVER SEGMENTS (cont.)

VERTICAL S-2

	Segment	Start	Stop	Supporting
1.	Gate	-15 sec	0 sec	S&L
2.	Entry	0 sec	$\phi>10^{\circ}$	CDT
			$\dot{h}>500$ ft/min	CDT
3.	First C/D Turn	$\phi>10^{\circ}$	$h_e>900$ ft	CDT
		$\dot{h}>500$ ft/min		
4.	Transition	$h_e>900$ ft	$h_e<900$ ft	CDT
5.	First D/C Turn	$h_e<900$ ft	$h_e<100$ ft	CDT
6.	Transition	$h_e<100$ ft	$h_e>100$ ft	CDT
7.	Second C/D Turn	$h_e>100$ ft	$h_e>900$ ft	CDT
8.	Transition	$h_e>900$ ft	$h_e<900$ ft	CDT
9.	Second D/C Turn	$h_e<900$ ft	$h_e<100$ ft	CDT
10.	Transition S&L	$h_e<100$ ft	$\phi<5$	CDT
			$\dot{h}<500$ ft/min	

VERTICAL S-3

	Segment	Start	Stop	Supporting
1.	Gate	-15 sec	0 sec	S&L
2.	Entry	0 sec	$\phi>10^{\circ}$	CDT
			$\dot{h}>500$ ft/min	
3.	First C/D Turn	$\phi>10^{\circ}$	$h_e>900$ ft	CDT
		$\dot{h}>500$ ft/min		
4.	Transition	$h_e>900$ ft	$h_e<900$ ft	CDT
5.	First D/C Turn	$h_e<900$ ft	$h_e<100$ ft	CDT
6.	Reverse Transition	$h_e<100$ ft	$h_e>100$ ft	CDT
7.	Second C/D Turn	$h_e>100$ ft	$h_e>900$ ft	CDT
8.	Transition	$h_e>900$ ft	$h_e<900$ ft	CDT
9.	Second D/C Turn	$h_e<900$ ft	$h_e<100$ ft	CDT
10.	Transition S&L	$h_e<100$ ft	$\phi<5^{\circ}$	CDT
			$\dot{h}<500$ ft/min	

TABLE 8. MANEUVER SEGMENTS (cont.)

AILERON ROLL

Segment	Start	Stop	Supporting
1. Gate	-15 sec	0 sec	S&L
2. Entry	0 sec	$\phi>15^{0}$	INV
3. First 1/2	$\phi>15^{0}$	$\phi>180^{0}$	INV
4. Second 1/2	$\phi>180^{0}$	$\phi>345^{0}$	INV
5. Recovery	$\phi>345^{0}$	$\phi>355^{0}$	S&L

LOOP

Segment	Start	Stop	Supporting
1. Gate	-15 sec	0 sec	S&L
2. First 1/4	0 sec	$\Theta>80^{0}$	C/D
3. Transition	$\Theta>80^{0}$	$\Theta>100^{0}$	INV
4. Second 1/4	$\Theta>100^{0}$	$\Theta>180^{0}$	INV
5. Third 1/4	$\Theta>180^{0}$	$\Theta>260^{0}$	INV
6. Transition	$\Theta>260^{0}$	$\Theta>280^{0}$	INV
7. Fourth 1/4	$\Theta>280^{0}$	$\Theta>350^{0}$	C/D
8. Recovery	$\Theta>350^{0}$	$\Theta>355^{0}$ $\phi<10^{0}$	S&L

IMMELMAN

Segment	Start	Stop	Supporting
1. Gate	-15 sec	0 sec	S&L
2. First 1/4	0 sec	$\Theta>80^{0}$	C/D
3. Transition	$\Theta>80^{0}$	$\Theta>100^{0}$	INV
4. Second 1/4	$\Theta>100^{0}$	$\Theta>165^{0}$	INV
5. Roll	$\Theta>165^{0}$	$\phi<5^{0}$	INV

TABLE 8. MANEUVER SEGMENTS (cont.)

SPLIT-S

Segment	Start	Stop	Supporting
1. Gate	-15 sec	0 sec	S&L
2. Entry	0 sec	$\Theta>10^{o}$	C/D
3. 180^{o} Roll	$\Theta>10^{o}$	$\phi>160^{o}$	INV
4. Transition	$\phi>160^{o}$	$\Theta<160^{o}$	INV
5. 3/4 Loop	$\Theta<160^{o}$	$\Theta<100^{o}$	INV
6. Transition	$\Theta<100^{o}$	$\Theta<80^{o}$	INV
7. 4/4 Loop	$\Theta<80^{o}$	$\Theta<20^{o}$	C/D
8. Recovery	$\Theta<20^{o}$	$\Theta<5^{o}$	S&L

BEAM ATTACK

Segment	Start	Stop	Supporting
1. Gate	-15 sec	0 sec	S&L
2. Turn to Attack Heading	0 sec	$\Psi=\Psi_A\pm5^{o}$ $\phi<5^{o}$	CBT
3. Maintain Attack Heading	$\Psi=\Psi_A\pm5^{o}$ $\phi<5^{o}$	$R_T<13NM$	S&L
4. Turn 30^{o} Toward Target	$R_T<13NM$	$\Delta\Psi>25^{o}$ $\phi<5^{o}$	CBT
5. Intercept 120 DTG at 7NM	$\Delta\Psi>25^{o}$ $\phi<5^{o}$	$R_T<7NM$	S&L
6. Initial 45^{o} Bank	$R_T<7NM$	$\phi>35^{o}$	CBT
7. Final Vectoring	$\phi>35^{o}$	$LA<15^{o}$ $.75NM<R_T<1.75NM$	CBT
8. Lock-on & Roll-out	$LA<15^{o}$ $.75NM<R_T<1.75NM$	$\phi<15^{o}$	CBT
9. Firing	$\phi<15^{o}$	Target Hit/Miss	S&L
10. Break-Away	Target Hit/Miss	$\phi>30^{o}$	CBT

TABLE 8. MANEUVER SEGMENTS (cont.)

FORWARD QUARTER ATTACK

Segment	Start	Stop	Supporting
1. Gate	-15 sec	0 sec	S&L
2. Turn to Attack Heading	0 sec	$\Psi=\Psi_A \pm 5^\circ$ $\phi<5^\circ$	CBT
3. Intercept 150 DTG at 9.5NM	$\Psi=\Psi_A \pm 5^\circ$ $\phi<5^\circ$	$R_T<9.5NM$	S&L
4. Initial 45° Bank	$R_T<9.5NM$	$\phi>35^\circ$	CBT
5. Final Vectoring	$\phi>35^\circ$	$LA<15^\circ$ $.75NM<R_T<1.75NM$	CBT
6. Lock-on & Roll-out	$LA<15^\circ$ $.75NM<R_T<1.75NM$	$\phi<15^\circ$	CBT
7. Firing	$\phi<15^\circ$	Target Hit/Miss	S&L
8. Break-Away	Target Hit/Miss	$\phi>30^\circ$	CBT

HEAD-ON ATTACK

Segment	Start	Stop	Supporting
1. Gate	-15 sec	0 sec	S&L
2. Turn to Attack Heading	0 sec	$\Psi=\Psi_A \pm 5^\circ$ $\phi<5^\circ$	CBT
3. Intercept 180 DTG at 13NM	$\Psi=\Psi_A \pm 5^\circ$ $\phi<5^\circ$	$R_T<13NM$	S&L
4. Initial 45° Bank	$R_T<13NM$	$\phi>35^\circ$	CBT
5. Final Vectoring	$\phi>35^\circ$	$LA<15^\circ$ $.75NM<R_T<1.75NM$	CBT
6. Lock-on & Roll-out	$LA<15^\circ$ $.75NM<R_T<1.75NM$	$\phi<15^\circ$	CBT
7. Firing	$\phi<15^\circ$	Target Hit/Miss	S&L
8. Break-Away	Target Hit/Miss	$\phi>35^\circ$	CBT

STRAIGHT & LEVEL SUB.

Segment	Start	Stop
1. Gate	-15 sec	0 sec
2. S&L	0 sec	60 sec

TABLE 8. MANEUVER SEGMENTS (cont.)

CLIMB/DIVE SUB. (Speed Constant-Climb/Dive 1000 feet)

Segment	Start	Stop
1. Gate	-15 sec	0 sec
2. Entry	0 sec	$\dot{h}>500$ ft/min
3. C/D	$\dot{h}>500$ ft/min	$h_e>900$ ft
4. Recovery	$h_e>900$ ft	$h_e>975$ ft

CLIMB/DIVE SUB. (Rate Constant-Climb/Dive 1000 feet)

Segment	Start	Stop
1. Gate	-15 sec	0 sec
2. Entry	0 sec	$\dot{h}>500$ ft/min
3. C/D	$\dot{h}>500$ ft/min	$h_e>900$ ft
4. Recovery	$h_e>900$ ft	$h_e>975$ ft

TURNS (Constant Bank 90° Turn)

Segment	Start	Stop
1. Gate	-15 sec	0 sec
2. Entry	0 sec	$\phi>25^{\circ}$
3. 90° Turn	$\phi>25^{\circ}$	$\Psi_e>81^{\circ}$
4. Roll-out	$\Psi_e>81^{\circ}$	$\phi<5^{\circ}$

CLIMBING/DIVING TURNS (Rate Constant-Climb/Dive 1000 feet, 90° Turn)

Segment	Start	Stop
1. Gate	-15 sec	0 sec
2. Entry	0 sec	$\dot{h}>500$ ft/min $\phi>10^{\circ}$
3. C/D Turn	$\dot{h}>500$ ft/min $\phi>10^{\circ}$	$\Psi_e>81^{\circ}$ $h_e>900$ ft
4. Recovery	$\Psi_e>81^{\circ}$ $h_e>900$ ft	$\phi<5^{\circ}$ $h_e>975$ ft

INVERTED FLIGHT (30 Seconds)

Segment	Start	Stop
1. Gate	-15 sec	0 sec
2. Roll	0 sec	$\phi>170^{\circ}$
3. Transition	$\phi>170^{\circ}$	5 sec
4. Inverted Flight	5 sec	35 sec

TABLE 9. DATA COLLECTION REQUIREMENTS

ALL MANEUVERS

System/Control Data		Procedures Data		
Segment	t	Sample Interval	Parameter	Limits
1	e	-5 to 0 sec	$\lvert\Psi_e\rvert$	$<10^{\circ}$
			$\lvert h_e\rvert$	<200 ft
			$\lvert V_e\rvert$	<20 KIAS
			$\lvert\phi_e\rvert$	$<5^{\circ}$
			$\lvert\dot{h}\rvert$	<500 ft/min

TURN PATTERN

System/Control Data								Procedures Data		
Segment	t	S_A	S_E	β	ϕ_e	h_e	V_e	Sample Interval	Parameter	Limits
2	e	s	s	r	-	r	r	0 to 3 sec	$\lvert\phi_e\rvert$	>5 sec
3	e	s	s	r	r	r	r	None	-	-
4	e	s	s	r	-	r	r	$-5^{\circ}<\phi<5^{\circ}$	$\lvert\Psi\rvert$	058° - 062°
5	e	s	s	r	r	r	r	None	-	-
6	e	s	s	r	-	r	r	$-5^{\circ}<\phi<5^{\circ}$	$\lvert\Psi\rvert$	358° - 002°
7	e	s	s	r	r	r	r	None	-	-
8	e	s	s	r	-	r	r	$-5^{\circ}<\phi<5^{\circ}$	$\lvert\Psi\rvert$	088° - 092°
9	e	s	s	r	r	r	r	None	-	-
10	e	s	s	r	-	r	r	$-5^{\circ}<\phi<5^{\circ}$	$\lvert\Psi\rvert$	358° - 002°
11	e	s	s	r	r	r	r	None	-	-
12	e	s	s	r	-	r	r	$-5^{\circ}<\phi<5^{\circ}$	$\lvert\Psi\rvert$	175° - 185°
13	e	s	s	r	r	r	r	None	-	-
14	e	s	s	r	-	r	r	$-5^{\circ}<\phi<5^{\circ}$	$\lvert\Psi\rvert$	358° - 002°

TABLE 9. DATA COLLECTION REQUIREMENTS (cont.)

VERTICAL S-1

	System/Control Data							Procedures Data		
Segment	t	S_A	S_E	β	Ψ_e	$\dot{h}$	V_e	Sample Interval	Parameter	Limits
2	e	s	s	r	r	-	r	0 to 1 sec	$\lvert\dot{h}\rvert$	>250 ft/min
3	e	s	s	r	r	r	r	None	-	-
4	e	s	s	r	r	-	r	$\lvert\dot{h}\rvert$ < 200 ft/min	$\lvert h_e\rvert$	950-1050 ft
5	e	s	s	r	r	r	r	None	-	-
6	e	s	s	r	r	-	r	$\lvert\dot{h}\rvert$ < 200 ft/min	$\lvert h_e\rvert$	<50 ft
7	e	s	s	r	r	r	r	None	-	-
8	e	s	s	r	r	-	r	$\lvert\dot{h}\rvert$ < 200 ft/min	$\lvert h_e\rvert$	950-1050 ft
9	e	s	s	r	r	r	r	None	-	-
10	e	s	s	r	r	-	r	0 to 1 sec	$\lvert h_e\rvert$	<100 ft

VERTICAL S-2

	System/Control Data							Procedures Data		
Segment	t	S_A	S_E	β	$\dot{\Psi}$	$\dot{h}$	V_e	Sample Interval	Parameter	Limits
2	e	s	s	r	-	-	r	0 to 3 sec	$\lvert\phi_e\rvert$	>10^{o}
									$\lvert\ddot{h}\rvert$	>250 ft/min
3	e	s	s	r	r	r	r	None	-	-
4	e	s	s	r	-	-	r	None	-	-
5	e	s	s	r	r	r	r	None	-	-
6	e	s	s	r	-	-	r	None	-	-
7	e	s	s	r	r	r	r	None	-	-
8	e	s	s	r	-	-	r	$\lvert\dot{h}\rvert$ < 200 ft/min	$\lvert h_e\rvert$	900-1100 ft
									$\lvert\Psi_e\rvert$	85^{o}-95^{o}
9	e	s	s	r	r	r	r	None	-	-
10	e	s	s	r	-	-	r	0 to 1 sec	$\lvert\Psi_e\rvert$	<5^{o}

TABLE 9. DATA COLLECTION REQUIREMENTS (cont.)

VERTICAL S-3

	System/Control Data							Procedures Data		
Segment	t	S_A	S_E	β	$\dot{\Psi}$	$\dot{h}$	V_e	Sample Interval	Parameter	Limits
2	e	s	s	r	-	-	r	0 to 3 sec	$\lvert\phi_e\rvert$	$>10^o$
									$\lvert\dot{h}\rvert$	>250 ft/min
3	e	s	s	r	r	r	r	None	-	-
4	e	s	s	r	-	-	r	$\lvert\dot{h}\rvert$ < 200 ft/min	$\lvert h_e\rvert$	900-1100 ft
									$\lvert\Psi_e\rvert$	85^o-95^o
5	e	s	s	r	r	r	r	None	-	-
6	e	s	s	r	-	-	r	$\lvert\dot{h}\rvert$ < 200 ft/min	$\lvert h_e\rvert$	<100 ft
									$\lvert\Psi_e\rvert$	175^o-185^o
									$\lvert\phi_e\rvert$	$<10^o$
7	e	s	s	r	r	r	r	None	-	-
8	e	s	s	r	-	-	r	$\lvert\dot{h}\rvert$ < 200 ft/min	$\lvert h_e\rvert$	900-1100 ft
									$\lvert\Psi_e\rvert$	85^o-95^o
9	e	s	s	r	r	r	r	None	-	-
10	e	s	s	r	-	-	r	0 to 1 sec	$\lvert\Psi_e\rvert$	$<5^o$

TABLE 9. DATA COLLECTION REQUIREMENTS (cont.)

AILERON ROLL

System/Control Data								Procedures Data		
Segment	t	S_A	S_E	β	Ψ_e	h_e	V_e	Sample Interval	Parameter	Limits
2	e	s	s	r	r	r	r	0 to 3 sec	$\|\phi_e\|$	$>15^o$
									Θ	$>10^o$
3	e	s	s	-	r	r	r	None	-	-
4	e	s	s	-	r	r	r	0 to 1 sec	$\|\Theta_e\|$	$<5^o$
5	e	s	s	r	r	r	r	0 to 3 sec	$\|\Psi_e\|$	$<5^o$
									$\|h_e\|$	<100 ft
									$\|\Theta_e\|$	$<5^o$

LOOP

System/Control Data										Procedures Data		
Segment	t	S_A	S_E	β	Th	Ψ_e	ϕ_e	G	α	Sample Interval	Parameter	Limits
2	e	s	s	r	s	r	r	r	r	0 to 1 sec	Θ	$>5^o$
3	e	s	s	r	s	-	r	-	r	0 to 1 sec	G	3.5-4.5
											α	>12 units
4	e	s	s	r	s	r	r	-	r	None	-	-
5	e	s	s	r	-	r	r	-	r	0 to 1 sec	Ψ_e	170^o-190^o
											V_e	>180 KIAS
											ϕ_e	170^o-190^o
6	e	s	s	r	-	-	r	-	r	None	-	- -
7	e	s	s	r	-	r	r	r	-	0 to 3 sec	G	2.5-4.5
											α	14-20 units
											Th	<95% (RPM)
8	e	s	s	r	s	r	r	-	-	0 to 3 sec	$\|\Psi_e\|$	$<10^o$
											$\|V_e\|$	100 KIAS
											G	.5-2.0

TABLE 9. DATA COLLECTION REQUIREMENTS (cont.)

IMMELMAN

	System/Control Data								Procedures Data		
Segment	t	S_A	S_E	β	Ψ_e	ϕ_e	G	α	Sample Interval	Parameter	Limits
2	e	s	s	r	r	r	r	-	0 to 1 sec	Θ	$>5^o$
3	e	s	s	r	-	r	-	r	0 to 1 sec	G	3.5-4.5
										α	>12 units
4	e	s	s	r	r	-	-	r	$\Theta < 15^o$	Ψ_e	170^o-190^o
										ϕ_e	170^o-190^o
5	e	s	s	r	r	-	-	-	0 to 1 sec	Ψ_e	170^o-190^o
										V	>180 KIAS
										$\lvert\Theta_e\rvert$	$<10^o$

SPLIT-S

	System/Control Data								Procedures Data		
Segment	t	S_A	S_E	β	Th	Ψ_e	ϕ_e	G	Sample Interval	Parameter	Limits
2	e	s	s	r	s	r	-	-	0 to 3 sec	$\lvert\phi_e\rvert$	$>10^o$
										Θ	$>5^o$
3	e	s	s	-	-	r	-	-	None	-	-
4	e	s	s	-	-	r	-	-	$-190^o<\phi<-170^o$	Θ	$>-20^o$
5	e	s	s	r	-	r	r	-	None	-	-
6	e	s	s	r	s	-	r	-	None	-	-
7	e	s	s	r	s	-	-	r	None	-	-
8	e	s	s	r	-	-	-	-	0 to 3 sec	Ψ_e	170^o-190^o
										G	.5-2

TABLE 9. DATA COLLECTION REQUIREMENTS (cont.)

BEAM ATTACK

	System/Control Data							Procedures Data		
Segment	t	S_A	S_E	β	h_e	V_e	ϕ_e	Sample Interval	Parameter	Limits
2	e	s	s	r	r	r	r	0 to 3 sec	$\lvert\phi_e\rvert$	$>10^0$
3	e	s	s	r	r	r	r	None	-	-
4	e	s	s	r	r	r	r	0 to 3 sec	$\lvert\phi_e\rvert$	$>10^0$
5	e	s	s	r	r	r	r	None	-	-
6	e	s	s	r	r	r	r	0 to 3 sec	$\lvert h_e\rvert$	<200 ft
									$\lvert V_e\rvert$	<20 KIAS
									$\lvert\phi_e\rvert$	$>15^0$
7	e	s	s	r	r	r	r	None	-	-
8	e	s	s	r	r	r	r	None	-	-
9	e	s	s	r	r	r	r	0 to 3 sec	$\lvert h_e\rvert$	<200 ft
									$\lvert V_e\rvert$	<20 KIAS
10	e	s	s	r	r	r	r	0 to 3 sec	$\lvert h_e\rvert$	<200 ft
									$\lvert V_e\rvert$	<20 KIAS

TABLE 9. DATA COLLECTION REQUIREMENTS (cont.)

FORWARD QUARTER ATTACK

	System/Control Data							Procedures Data		
Segment	t	S_A	S_E	β	h_e	V_e	ϕ_e	Sample Interval	Parameter	Limits
2	e	s	s	r	r	r	r	0 to 3 sec	$\lvert\phi_e\rvert$	$>10^o$
3	e	s	s	r	r	r	r	None	-	-
4	e	s	s	r	r	r	r	0 to 3 sec	$\lvert h_e\rvert$	<200 ft
									$\lvert V_e\rvert$	<20 KIAS
									$\lvert\phi_e\rvert$	$>15^o$
5	e	s	s	r	r	r	r	None	-	-
6	e	s	s	r	r	r	r	None	-	-
7	e	s	s	r	r	r	r	0 to 3 sec	$\lvert h_e\rvert$	<200 ft
									$\lvert V_e\rvert$	<20 KIAS
8	e	s	s	r	r	r	r	0 to 3 sec	$\lvert h_e\rvert$	<200 ft
									$\lvert V_e\rvert$	<20 KIAS

TABLE 9. DATA COLLECTION REQUIREMENTS (cont.)

HEAD-ON ATTACK

	System/Control Data							Procedures Data		
Segment	t	S_A	S_E	β	h_e	V_e	ϕ_e	Sample Interval	Parameter	Limits
2	e	s	s	r	r	r	r	0 to 3 sec	$\lvert\phi_e\rvert$	$>10^o$
3	e	s	s	r	r	r	r	None	-	-
4	e	s	s	r	r	r	r	0 to 3 sec	$\lvert h_e\rvert$	<200 ft
									$\lvert V_e\rvert$	<20 KIAS
									$\lvert\phi_e\rvert$	$>15^o$
5	e	s	s	r	r	r	r	None	-	-
6	e	s	s	r	r	r	r	None	-	-
7	e	s	s	r	r	r	r	0 to 3 sec	$\lvert h_e\rvert$	<200 ft
									$\lvert V_e\rvert$	<20 KIAS
8	e	s	s	r	r	r	r	0 to 3 sec	$\lvert h_e\rvert$	<200 ft
									$\lvert V_e\rvert$	<20 KIAS

STRAIGHT & LEVEL SUB.

	System/Control Data								Procedures Data		
Segment	t	S_A	S_E	β	Ψ_e	h_e	V_e	ϕ	Sample Interval	Parameter	Limits
2	e	s	s	r	r	r	r	r	0 to 3 sec	$\lvert\dot{h}\rvert$	<500 ft/min

TABLE 9. DATA COLLECTION REQUIREMENTS (cont.)

CLIMB/DIVE SUB. (Speed Constant-Climb/Dive 1000 feet)

	System/Control Data								Procedure Data		
Segment	t	S_A	S_E	β	Ψ_e	$\dot{h}$	V_e	ϕ_e	Sample Interval	Parameter	Limits
2	e	s	s	r	r	-	r	r	0 to 1 sec	$\lvert\dot{h}\rvert$	<250 ft/min
3	e	s	s	r	r	r	r	r	None	-	-
4	e	s	s	r	r	-	r	r	None	-	-
5	e	s	s	r	r	r	r	r	0 to 3 sec	$\lvert\dot{h}\rvert$	<500 ft/min

CLIMB/DIVE SUB. (Rate Constant-Climb/Dive 1000 feet)

	System/Control Data								Procedures Data		
Segment	t	S_A	S_E	β	Ψ_e	$\dot{h}$	V_e	ϕ_e	Sample Interval	Parameter	Limits
2	e	s	s	r	r	-	r	r	0 to 1 sec	$\lvert\dot{h}\rvert$	>250 ft/min
3	e	s	s	r	r	r	r	r	None	-	-
4	e	s	s	r	r	-	r	r	None	-	-
5	e	s	s	r	r	r	r	r	0 to 3 sec	$\lvert\dot{h}\rvert$	<500 ft/min

TURNS (Constant Bank 90° Turn)

	System/Control Data							Procedures Data		
Segment	t	S_A	S_E	β	h_e	V_e	ϕ_e	Sample Interval	Parameter	Limits
2	e	s	s	r	r	r	-	0 to 1 sec	$\lvert\phi_e\rvert$	>10°
3	e	s	s	r	r	r	r	None	-	-
4	e	s	s	r	r	r	-	0 to 1 sec	$\lvert\Psi_e\rvert$	88°-92°

TABLE 9. DATA COLLECTION REQUIREMENTS (cont.)

CLIMBING/DIVING TURNS (Rate Constant-Climb/Dive 1000 feet, 90° Turn)

	System/Control Data							Procedures Data		
Segment	t	S_A	S_E	β	$\dot{h}$	V_e	$\dot{\phi}$	Sample Interval	Parameter	Limits
2	e	s	s	r	-	r	-	0 to 3 sec	$\lvert\dot{h}\rvert$	>250 ft/min
									$\lvert\phi_e\rvert$	$>10^\circ$
3	e	s	s	r	r	r	r	None	-	-
4	e	s	s	r	-	r	-	0 to 3 sec	$\lvert\dot{h}\rvert$	<500 ft/min
									$\lvert\Psi_e\rvert$	88°-92°

INVERTED FLIGHT (30 Seconds)

	System/Control Data						Procedures Data		
Segment	t	S_A	β	Ψ_e	h_e	V_e	Sample Interval	Parameter	Limits
2	e	-	-	r	r	r	0 to 3 sec	$\lvert\phi_e\rvert$	$>10^\circ$
								Θ	$>5^\circ$
3	e	-	-	r	r	r	None	-	-
4	e	s	r	r	r	r	None	-	-

TABLE 10. DATA SAMPLING RATES

Parameters	Rate (in milliseconds)
h	250
$\dot{h}$	250
V	500
ϕ	250
$\dot{\phi}$	100
β	250
ψ	250
$\dot{\psi}$	250
α	250
Θ	250
$\dot{\Theta}$	100
G	250
Stick A	100
Stick E	100
THROTR	500

TABLE 11. PARAMETER WEIGHTING FACTORS

Parameter	Symbol	Weighting Factors
Altitude	h_e	0.25
Bank Angle	ϕ	10.00
Heading	Ψ	5.00
Rate of Climb	$\dot{h}$	0.10
Rate of Turn	$\dot{\Psi}$	50.00
Airspeed	V	5.00
Sideslip	β	50.00
Stick E	-	10.00
Stick A	-	10.00
Throttle	THROTR	100.00
Normal Acceleration	G	100.00
Angle of Attack	α	20.00

APPENDIX D

OUTPUT

The general categories of output generated by the BIFM program consist of:

a. Cockpit Displays

b. Instructor Displays

c. Audio Instruction

d. Student Records

An Evans and Sutherland (E&S) graphics display installed in the TRADEC cockpit was used to brief the student on each maneuver and the characteristics of each level within the maneuver. The display portrayed the required maneuver in a pictoral drawing. Critical parameters for the different segments of each maneuver were displayed where relevant. In all cases, initial and terminal altitude, airspeed, and heading were identified. The display was initiated for maneuver briefing in the system initialization function. The display remained on until feedback messages had been delivered to the student.

In addition to the maneuver display, a stylized clock was displayed in the upper left corner of the display. The clock was required to synchronize the maneuver initialization with the computer time. (The only clock in the cockpit was a standard aircraft elapsed time-hand wind type which could not be synchronized with the computer.) The displayed clock displayed only a second hand which was initialized at fifteen seconds to the hour when the simulator was ready for the start of the trial. Figures 25, 26 and 27 are typical displays of the briefing mode.

The display was also used for general feedback. Figure 28 shows the display of feedback data for completed and incompleted trials.

The instructor or training manager has two graphics displays available to him as well as the computer operating console and the TRADEC console which contains a duplicate of the cockpit instruments. One of the displays is a repeater of the cockpit

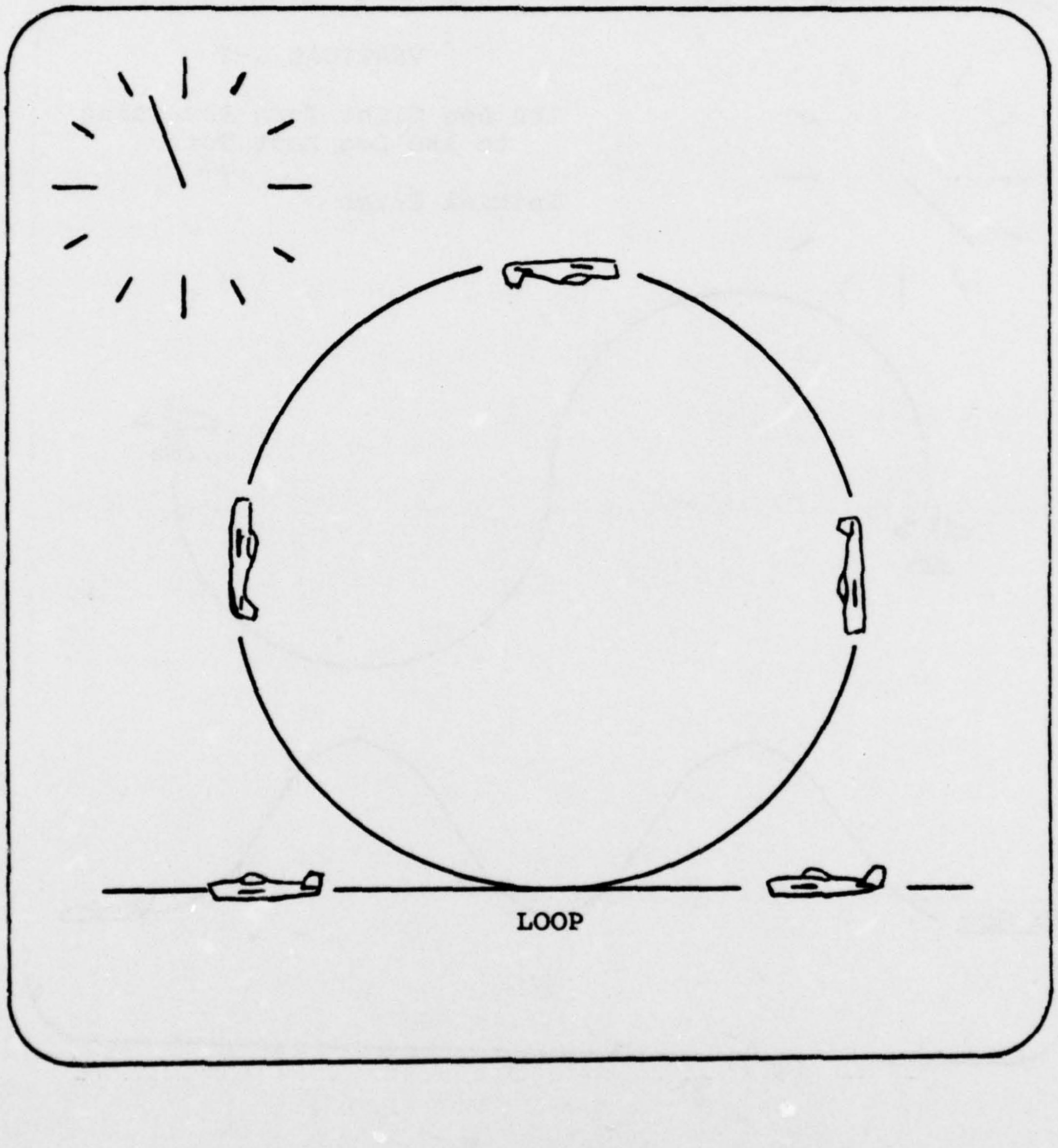


Figure 25. Student display loop maneuver.

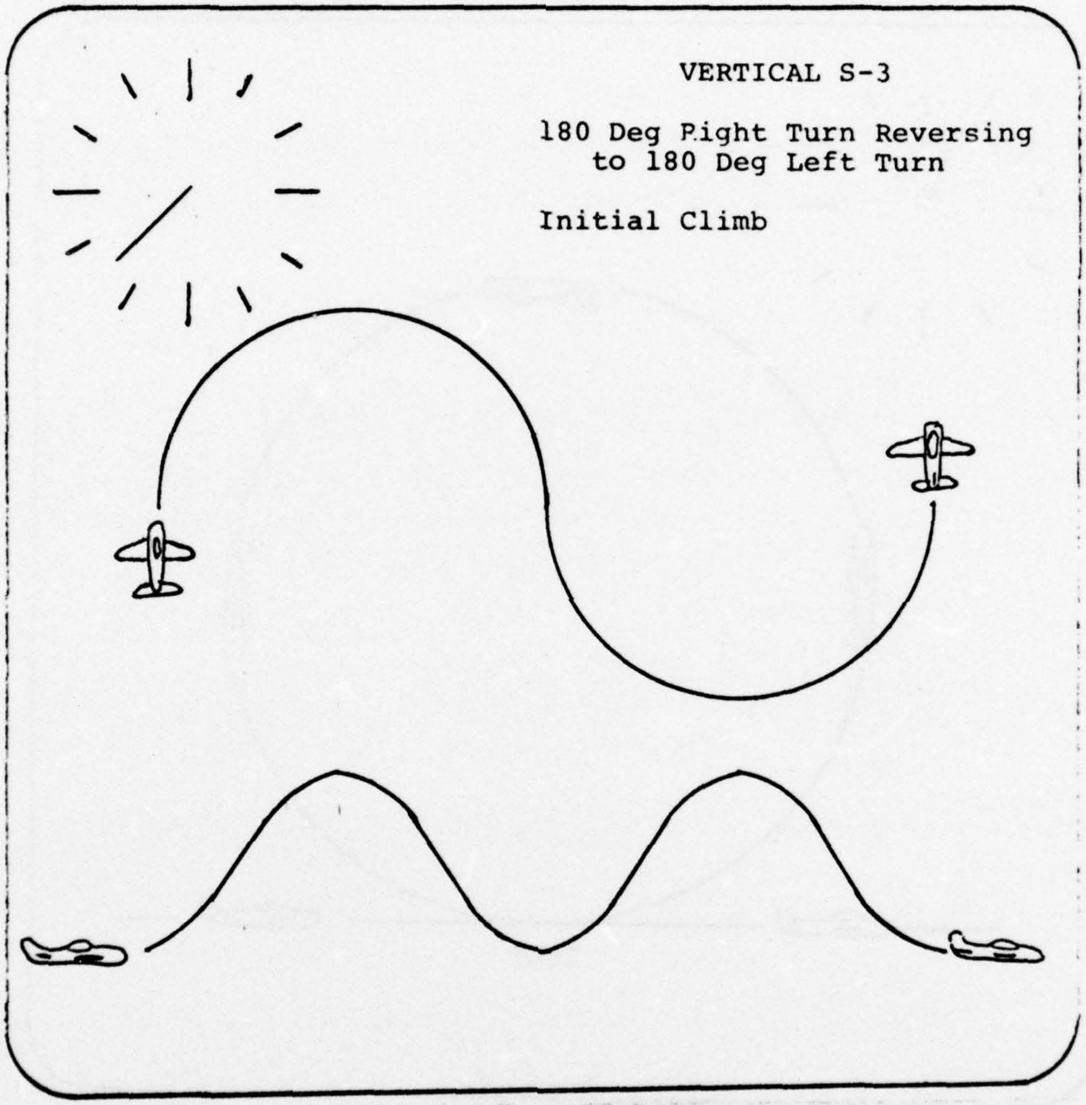


Figure 26. Student display Vertical S-3.

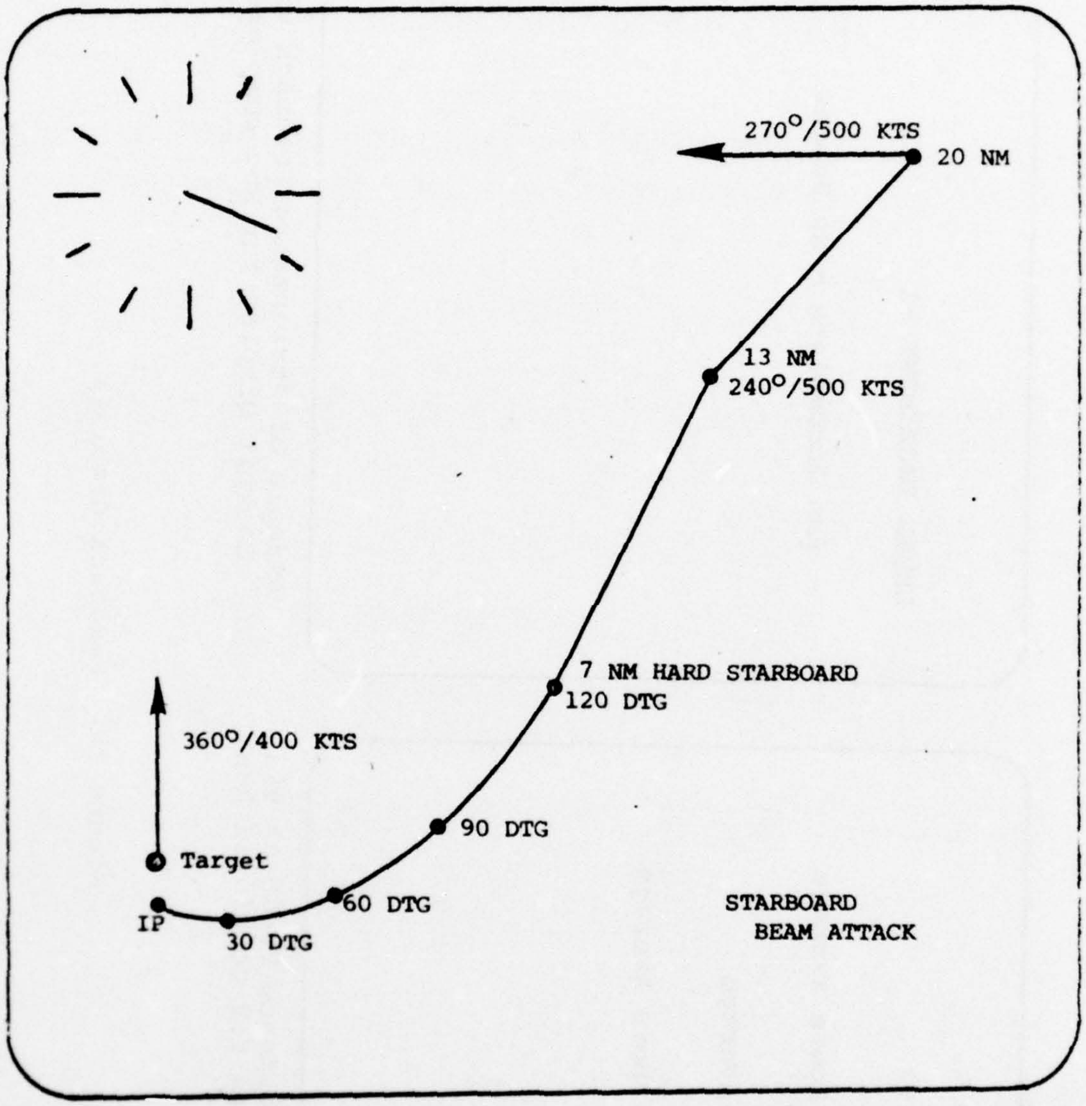


Figure 27. Student display beam attack.

LEVEL INCREMENT +2

System	Above Average
Control	Average
Procedure	Above Average

Example of Performance Feedback via Cockpit Display for Completed Run

LEVEL INCREMENT -1

Run Incomplete - No Scores

Example of Performance Feedback via Cockpit Display for Non-completed Run

Figure 28. Feedback displays.

display. Thus, the instructor will at all times have available the same display that the student is using for the maneuvers.

The more important display utilizes the IDIIOM terminal of the TRADEC system. The display provides the instructor key data on the student's performance for the trial underway including error plots for the basic governing parameters for the maneuver. Figure 29 shows a sample display. Table 12 lists the parameters to be displayed for each maneuver.

The air-to-air maneuvers produce a different format for the IDIIOM display. Two relative plots of the interceptor with respect to the target are shown. Figure 30 illustrates this display.

The display will be energized 15 seconds before the minute (when the trial is started) and remains on until the maneuver is terminated or completed. If the maneuver is not initiated, the display is cancelled and reinitialized with the overall simulation.

An audio instructor mode is utilized at the lower levels of maneuver training. It is initiated at level 5 and below. Only key parameters are monitored and appropriate instructions generated if the error in the parameter exceeds criterion value. The basic logic flow is shown in Figure 31. Table 13 lists the typical parameter bounds and messages to be output for the precision and confidence maneuvers. Table 14 contains the messages used in the air-to-air maneuvers.

Audio instruction is very limited during the confidence maneuvers because of the short duration of these maneuvers. The system requires approximately .5 seconds for each word.

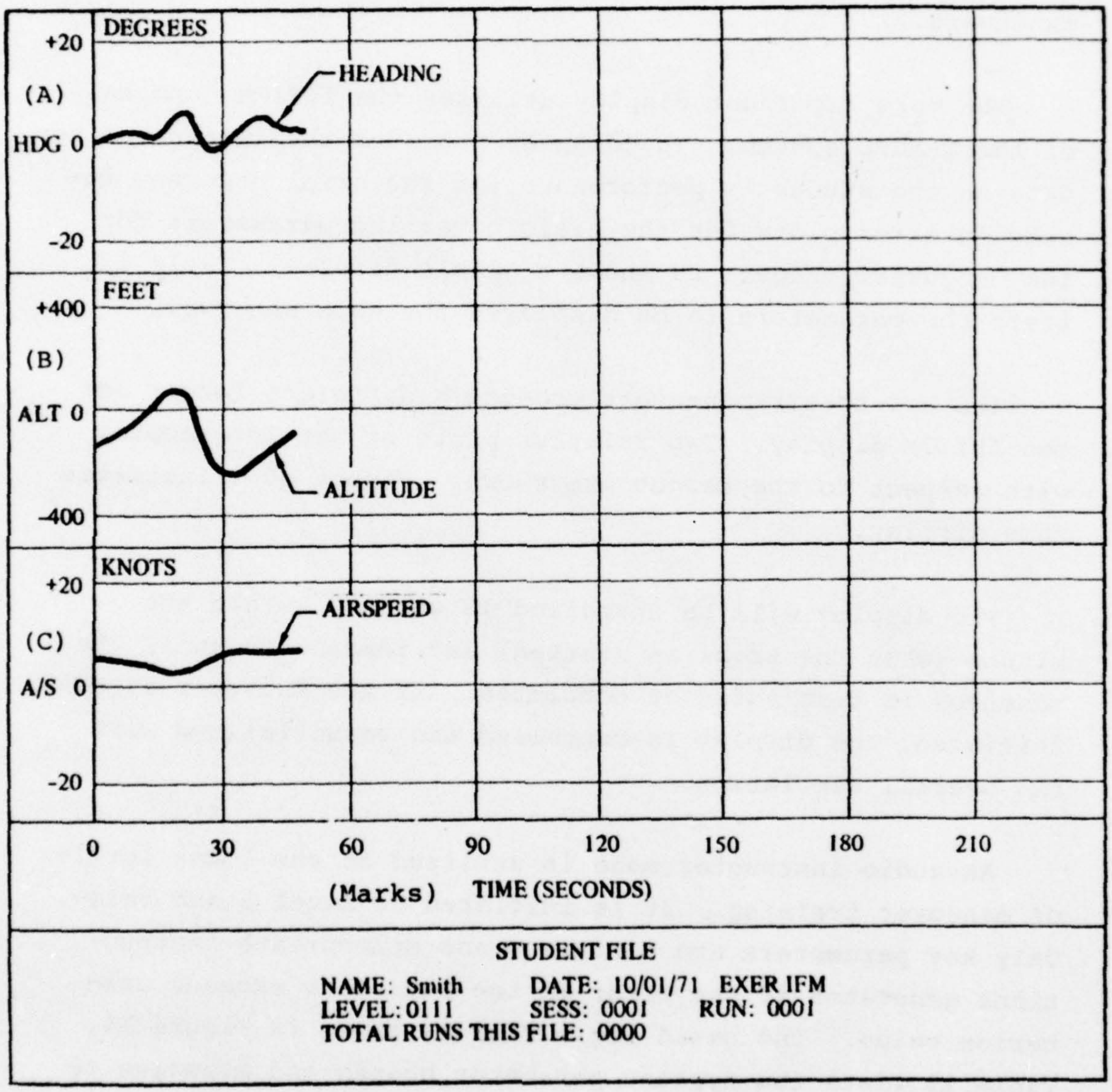


Figure 29. Sample instructor data display.

TABLE 12. INSTRUCTOR DISPLAY PARAMETERS

MANEUVER #	Title	Plot A Parameter	Limits	Plot B Parameter	Limits	Plot C Parameter	Limits	Time Scale	Marks
A	Turn Pattern	V_e	40 kts	h_e	400'	ϕ_e	20°	400"	50"
B	Vertical S-1	V_e	40 kts	$\dot{h}$	1000'/'	Ψ_e	20°/'	400"	50"
C	Vertical S-2	V_e	40 kts	$\dot{h}_e$	1000'/'	$\dot{\Psi}_e$	1°/"	400"	50"
D	Vertical S-3	V_e	40 kts	$\dot{h}_e$	1000'/'	$\dot{\Psi}_e$	1°/"	400"	50"
E	Aileron Roll	V_e	40 kts	h_e	400'	Ψ	20°	40"	5"
F	Loop	α_e	5 units	G_e	1g	Ψ_e	20°	80"	10"
G	Immelmann	α_e	5 units	G_e	1g	Ψ_e	20°	80"	10"
H	Split S	α_e	5 units	G_e	1g	Ψ_e	20°	80"	10"
SUB-SYLLABUS									
I	St & Lvl	V_e	40 kts	h_e	400'	Ψ_e	20°	200"	25"
J	C & D (Speed)	V_e	40 kts	$\dot{h}_e$	1000'/'	Ψ_e	20°	200"	25"
K	C & D (Rate)	V_e	40 kts	$\dot{h}_e$	1000'/'	Ψ_e	20°	200"	25"
L	Turns	V_e	40 kts	h_e	400'	ϕ_e	20°	200"	25"
M	C & D Turns	V_e	40 kts	$\dot{h}_e$	1000'/'	Ψ_e	1°/"	200"	25"
N	Inverted Flight	V_e	40 kts	h_e	400'	Ψ_e	20°	80"	5"

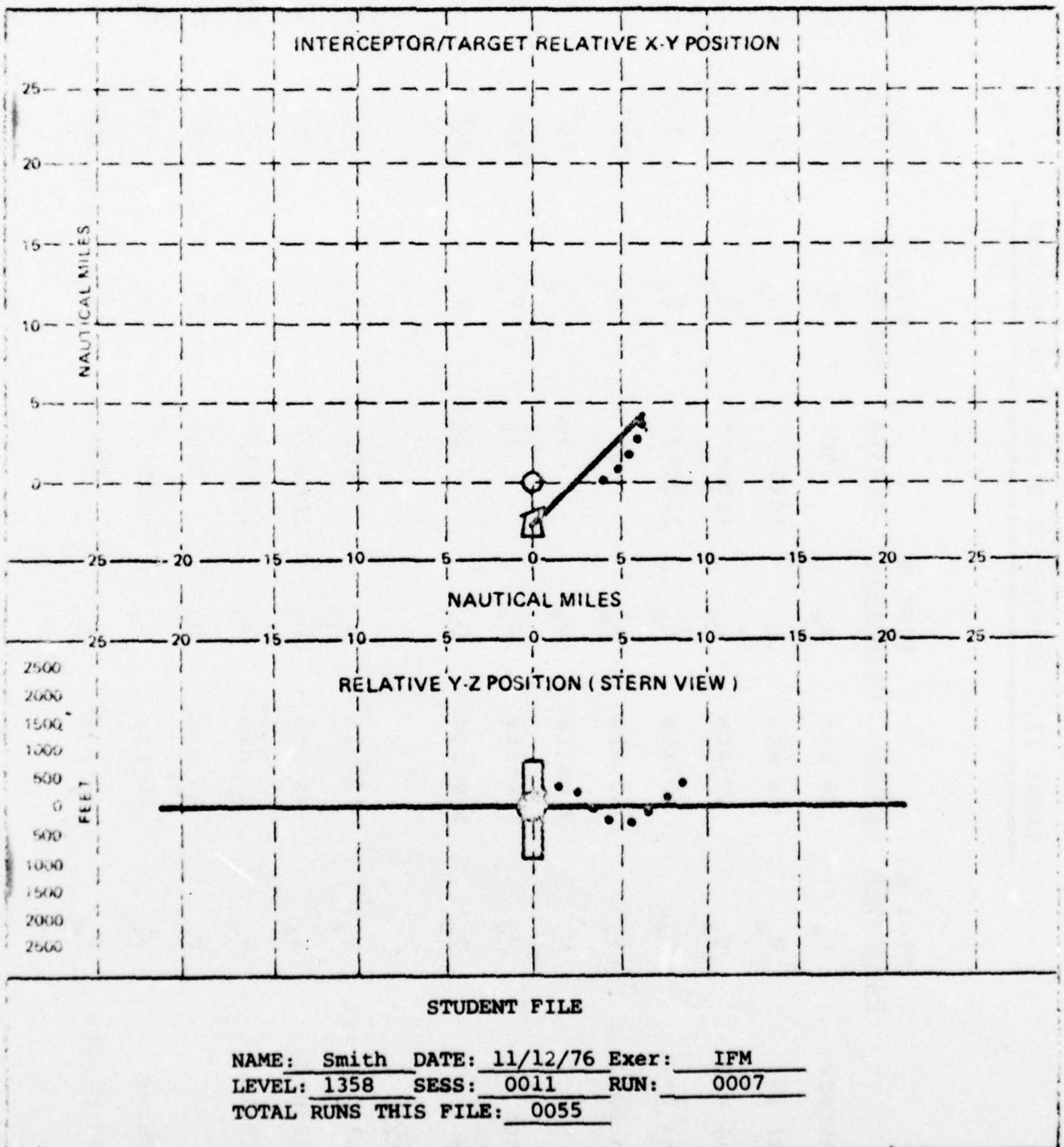


Figure 30. Diagram of Air-to-Air Display

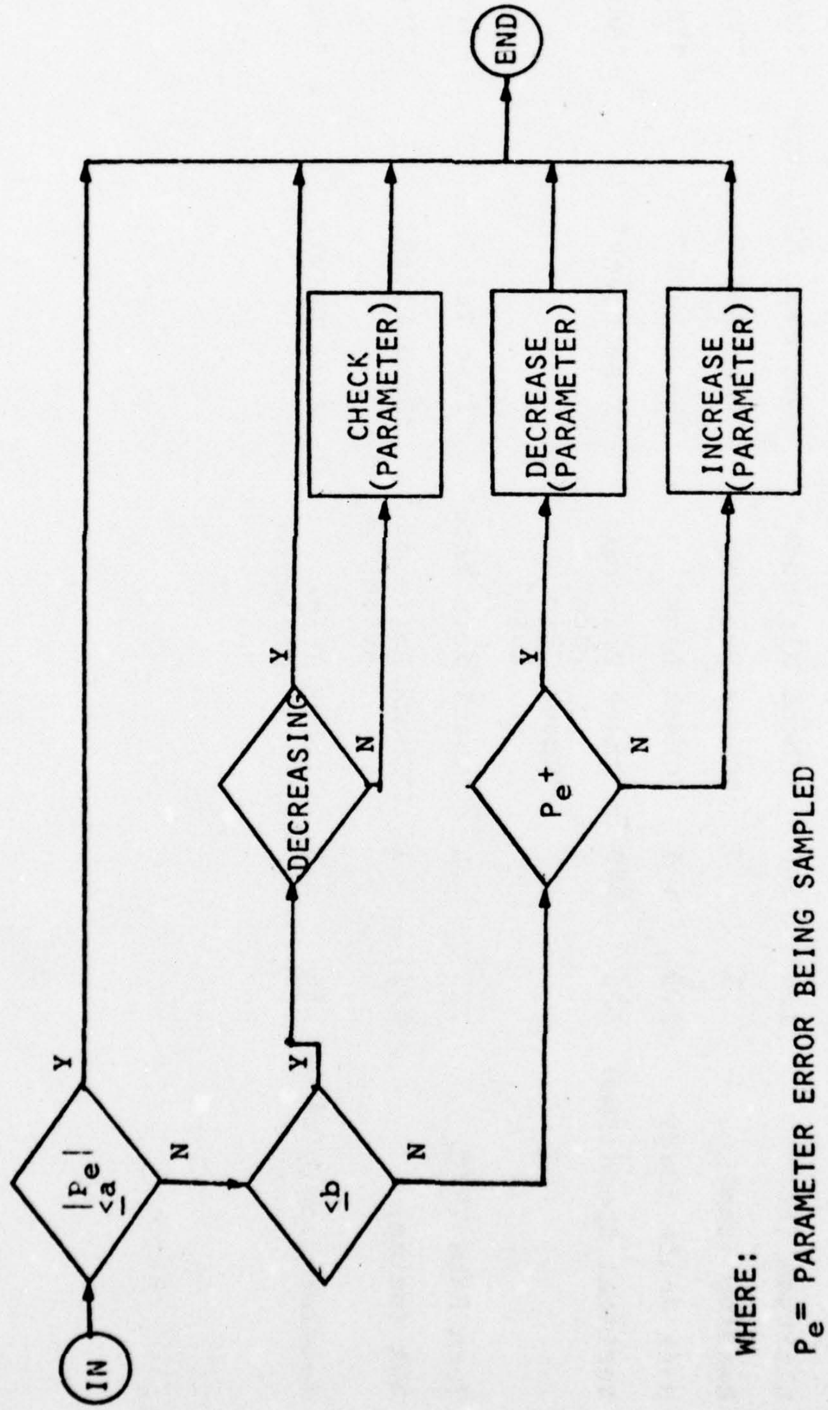


Figure 31. Error monitoring flow.

TABLE 13. ERROR MESSAGES AND TOLERANCE

Parameter	Tolerance Check	Tolerance Error	Check MSG	+Error MSG	-Error MSG
Speed (Knots)	10	20	"Check Speed"	"Decrease Speed"	"Increase"
Altitude (Ft)	100	200	"Check Altitude"	"Decrease Altitude"	"Increase"
Heading (Deg)	5	7	"Check Heading	"Turn Left"	"Turn Right"
Bank Angle (Deg)	2.5	5	"Check Bank"	"Ease Bank"	"Increase"
Vertical Speed(fpm)	100	200	"Check Descent Rate" "Check Climb Rate"	"Ease Power"	"Add Power"
Turn Rate (^{o}/")	.25	.5	"Check Turn Rate"	"Ease Turn"	"Increase
AOA (units)	1/2	1	"Check Angle of Attack"	"Ease Pitch"	"Increase"
Acceleration(g's)	.25	.5	"Check Stick Pressure"	"Ease Stick"	"Pull"

TABLE 14. AIR-TO-AIR MESSAGES

Vector XXX for attack heading, speed 500 knots, angels fifteen; Target one aircraft, fifteen thousand; Target heading 360, speed 400 knots.

Attack heading is XXX, angels fifteen, speed 500 knots.

Steady on attack vector; Target XXX (bearing) at XX (range); Take radar control for final attack.

Assigned altitude is fifteen thousand feet.

Assigned airspeed is 500 knots.

Assigned heading is XXX.

Hard Starboard (Port).

Ease Bank.

Hold Bank.

Harder Bank.

Turn Right (Left), heading XXX.

Heading is good.

Go down.

Hold altitude.

Climb.

Reduce Speed.

Hold Speed.

Increase Speed.

Break off attack to Starboard (Port).

The typical instruction, therefore, takes at least one second to complete. Some of the confidence maneuvers require only several seconds to complete. The list of available words in the voice system is contained in Table 16.

A flight envelope has been created for the training trials. If the student flies beyond the limits, the simulator is frozen and messages are output directing him to stop controlling the aircraft and the reason for the abort. The basic criteria reflect incipient crashes or loss of control. While recovery from unusual attitudes is a part of flight training, it is not considered a part of the basic instrument flight maneuvers syllabus. The freeze criteria are shown in Table 15.

TABLE 15. FREEZE CRITERIA

Angle-of-Attack	>25 Units
Acceleration	> 6 Units
Vertical Speed	>10,000 Feet Per Minute
Altitude	< 1,000 Feet
Heading Rate	> 6 Degrees Per Second

Figure 32 is a logic flow of the freeze function and identifies the message output following each freeze condition.

Feedback data is provided the student on both knowledge and perceptual motor skill. The feedback is accomplished using three different media, i.e., the E&S display, the voice system, and the instructor.

The first feedback occurs at the conclusion of the trial after the final score has been computed. If a score above criterion has been achieved, the voice system outputs a "Good Run" message.

TABLE 16 . VOICE SYSTEM WORD LIST

COGNITRONICS VOCABULARY (ALPHABETIC)

21 above	A5 clear	6B feet	70 is
61 acknowledge	66 clearance	0E fifty	B0 knots
A1 add	26 cleared	0C fifteen	31 land
24 adjust	A6 climb	AB final	32 leg
13 ahead	27 complete	07 five	B1 left
4A air	A7 contact	56 flaps	18 level
62 altitude	5E control	2C flight	72 line
A2 and	54 correct	30 formation	0B list
4B angels	A8 correction	86 four	B2 low
53 angle	29 course	6C from	73 mach
23 approach	22 craft	AC further	33 maintain
63 approaching	68 cross	2D glide	34 miles
93 assigned	94 decrease	4E go	B4 minimum
A3 at	A9 degrees	4C going	58 minus
6A attack	15 descend	6D good	35 minute
74 attitude	2A descent	49 half	75 missed
14 back	55 dive	78 hard	8E more
96 bank	AA down	2E heading	B5 nautical
A4 begin	95 ease	0A high	36 navy
64 behind	0D easy	AE hold	48 nine
25 below	4D __ed	8C holding	76 no
8A brake	08 eight	2F hundred	19 nose
88 __board	8B engine	6F if	37 not
11 bomb	8D __er	AF in	B6 now
3C __bound	16 establish	97 increase	B7 of
28 center	2B execute	57 __ing	59 off
65 check	1F fast	44 I.P.	77 okay

TABLE 16. VOICE SYSTEM WORD LIST (cont.)

COGNITRONICS VOCABULARY (ALPHABETIC)

38 on	9A set	01 time	05 your
85 one	87 seven	6E (tone, 1000 Hz)	45 zero
50 out	BD sight	A0 touchdown	92 zulu
B8 over	00 (silence)	41 transmission	
39 path	40 (silence)	60 trim	
79 pattern	80 (silence)	81 turn	
B9 per	47 six	5C twenty	
0F percent	3E slightly	06 two	
3A pitch	9E slow	71 __ty	
9F place	5B speed	02 under	
5F plan	17 standard	1D up	
1A plus	7E star	51 vary	
7A point	9B start	42 vector	
4F port	7D steady	82 visual	
5A power	91 steer	03 visually	
BA precision	1C stick	98 __ward	
99 pressure	1B stop	5D watch	
89 radar	BE take	AD way	
3B rate	67 target	43 well	
7B received	69 __teen	83 wheels	
10 reduce	90 ten	04 wind	
8F reverse	3F the	9D wings	
BB right	7F thirty	1E with	
7C roll	BF thousand	B3 wrong	
09 route	46 three	12 xray	
BC run	20 threshold	52 yankee	
3D seconds	9C throttles	84 yaw	

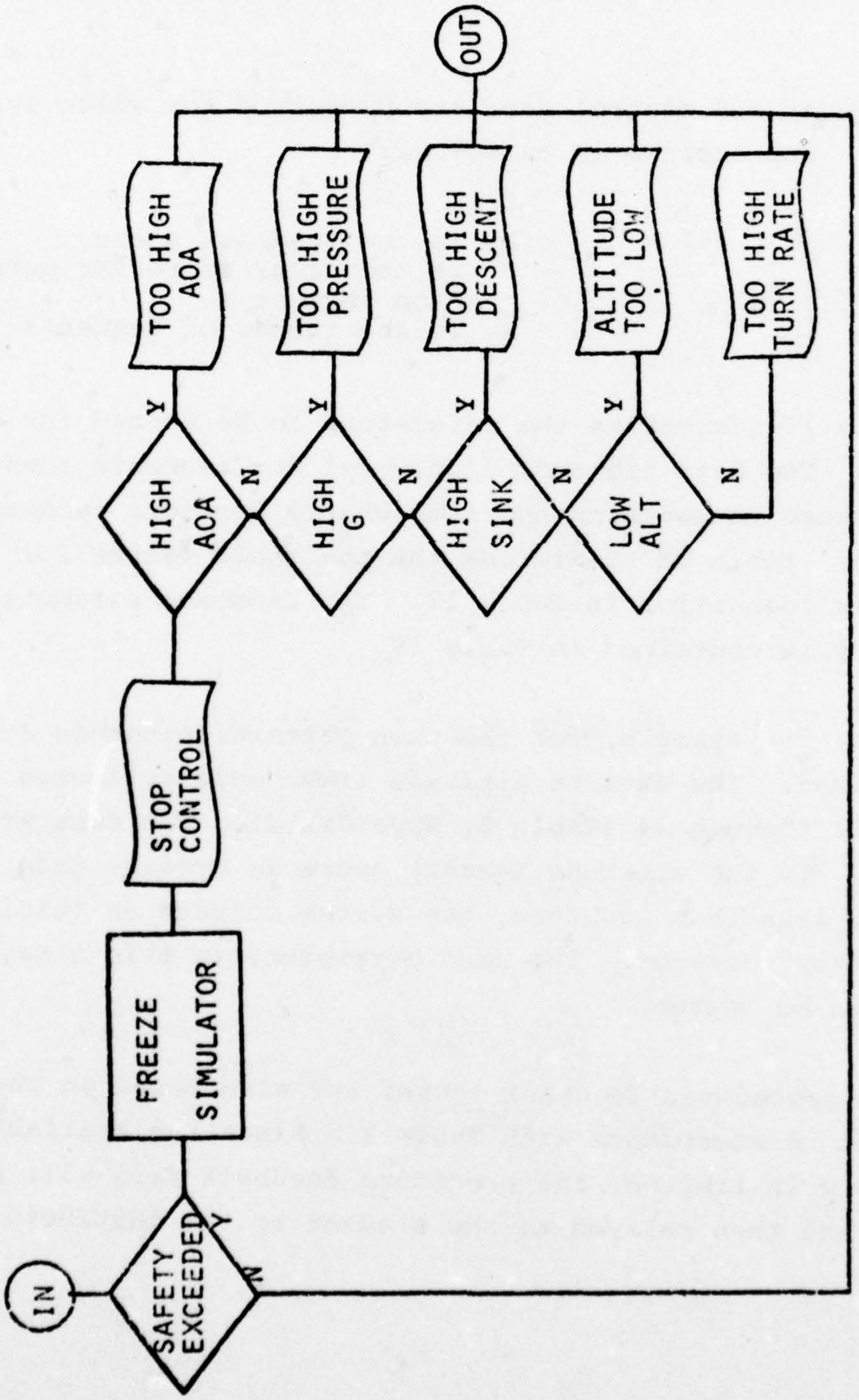


Figure 32. Safety freeze flow.

Other feedback data are separately calculated. The data collected for each maneuver as identified in Appendix C are utilized. Both maneuver, control and procedures data are utilized.

Maneuver and control data are processed for voice system feedback. The scoring is as follows:

$$M_F = \frac{\sum_{1}^{N} P_n}{N}$$

Where:
M_F is the feedback score
P is the error score for parameter P on segment n
N is the number of segments

Table 17 identifies the parameters to be scored for each maneuver. The data are scored only for the segments identified. Figure 33 contains the flow charts for this feedback procedure. Table 18 identifies the threshold values for the parameters identified in Table 17. The feedback parameter vocabulary is contained in Table 19.

Thus, for example, for the turn pattern, altitude data are scored first. The data on altitude (rms) were collected for segments 2 through 14 (Table 9, Appendix C). The data are averaged. If the altitude (error) score is greater than 100 feet, but less than 200 feet, the system outputs an "altitude control okay" message. The next parameter, in this case, speed, would then be scored.

The procedures feedback scores are also based on the data collected in accordance with Table 9. Since the available vocabulary is limited, the procedure feedback data will be printed and then relayed to the student by the instructor.

TABLE 17. VOICE FEEDBACK AND MANEUVER

MANEUVER	PARAMETER			Stick		
				A	E	
Turn Pattern	h	V	ø	A	E	Throttle
Vertical S-1	$\dot{h}$	V	ψ	A	E	Throttle
S-2	$\dot{h}$	$\dot{\psi}$	V	A	E	Throttle
S-3	$\dot{h}$	$\dot{\psi}$	V	A	E	Throttle
Penetration	$\dot{h}$	ψ	-	A	E	Throttle
Aileron Roll	$\dot{ø}$	h	-	A	E	Throttle
Wingover	-	-	-	A	E	Throttle
Barrel Roll	g	-	-	A	E	Throttle
Loop	ø	-	-	A	E	Throttle
Half Cuban Eight	ø	-	-	A	E	Throttle
Immelman	ø	-	-	A	E	Throttle
Split S	ø	-	-	A	E	Throttle
Climbs & Dives (V)	ψ	V	$\dot{h}$	A	E	Throttle
Climbs & Dives (S,h)	ψ	V	$\dot{h}$	A	E	Throttle
Turns (angle)	V	ø	h	A	E	Throttle
Turns (½ SR)	V	$\dot{ø}$	h	A	E	Throttle
Climbs & Dives (Turns)	V	$\dot{ø}$	$\dot{h}$	A	E	Throttle
Inverted Flight	V	h	ψ	A	E	Throttle

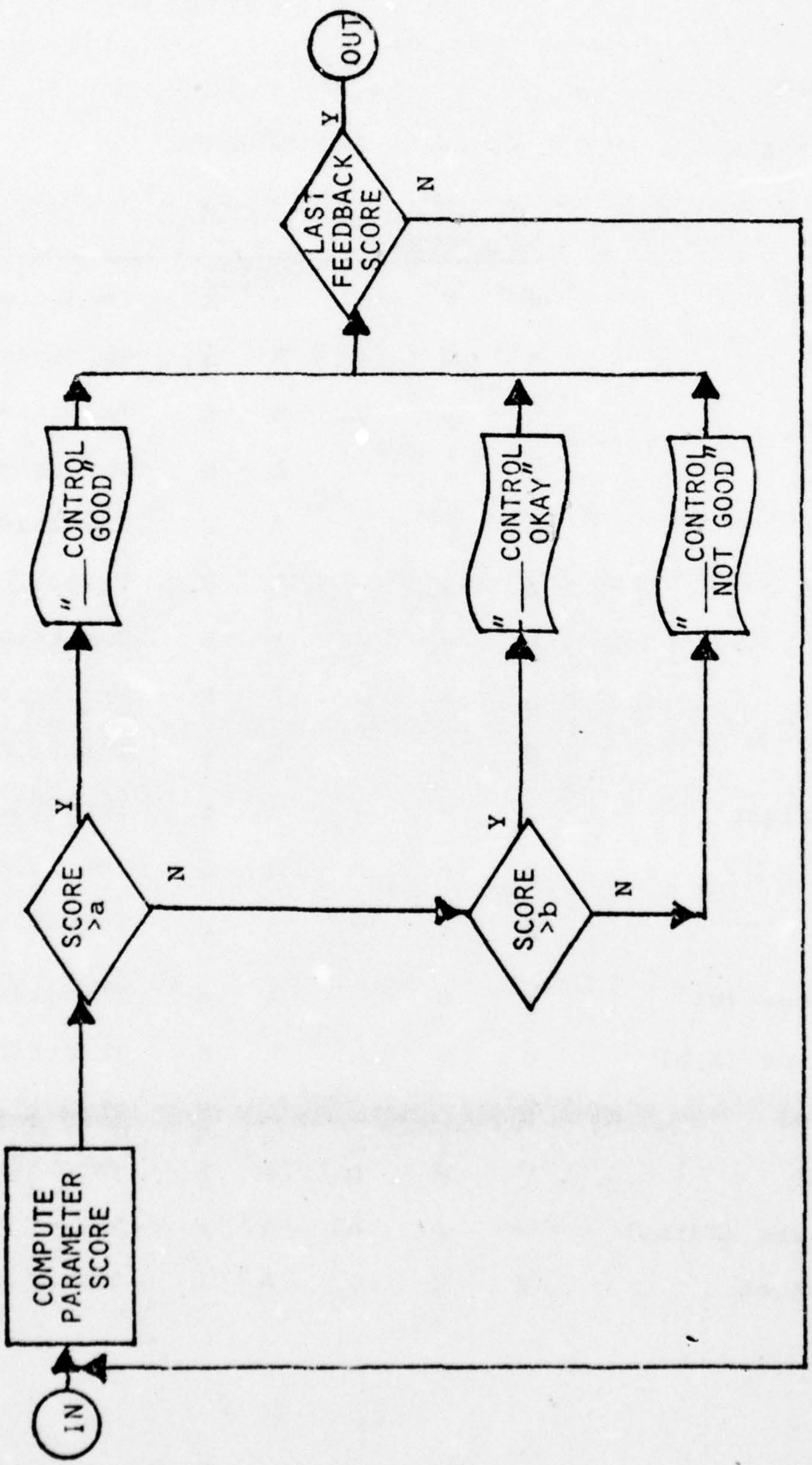


Figure 33. Verbal feedback flow.

TABLE 18. VOICE FEEDBACK THRESHOLDS

PARAMETER	Score "GOOD"	"OKAY"	"NOT GOOD"
h_e	$\leq$100'	$\leq$200'	>200'
V_e	$\leq$ 10kts	$\leq$ 20kts	> 20kts
ϕ_e	$\leq$ 5°	$\leq$ 10°	> 10°
ψ_e	$\leq$2.5°	$\leq$ 5°	> 5°
$\dot{\psi}_e$	$\leq$ .5°/"	$\leq$ .1°/"	> .1°/"
$\dot{\phi}_e$	$\leq$ 2°/"	$\leq$ 4°/"	> 4°/"
$\dot{h}_e$	$\leq$100'/'	$\leq$200'/'	>200'/'
g_e	$\leq$ ½g	$\leq$ 1g	> 1g
Stick A	$\leq$ X°	$\leq$ Y°	> Y°
Stick E	$\leq$ X°	$\leq$ Y°	> Y°
Throttle	$\leq$ X°	$\leq$ Y°	> Y°

TABLE 19. FEEDBACK VOCABULARY

Parameter	Word
h_e	"ALTITUDE"
V_e	"SPEED"
ϕ	"BANK"
ψ	"HEADING"
$\dot{\psi}$	"TURN RATE"
$\dot{\phi}$	"BANK RATE"
$\dot{h}$	"ALTITUDE RATE"
Stick A	"ROLL"
Stick E	"PITCH"
Throttle	"THROTTLES"

Segment two's feedback score is computed at zero time as follows:

$$F_{S2} = 1 \text{ if all conditions in Table 9 are met}$$
$$= 0 \text{ otherwise}$$

If the score is 1, the printer prints an "anticipated well" message. If not, it prints "did not anticipate".

A student record in the form of a line printer listing is provided for each trial. Figure 34 is a sample student record for the air-to-air beam attack.

The first three lines of the record contain student and maneuver ID and conditions, i.e., Student Name, Date, Flight (Session) Number, Maneuver Type, etc. The next four lines identify the assigned and actual entry parameters for the trial, i.e., Altitude, Airspeed, Heading, etc. At this point, the data collected for each segment of the trial is listed by segment number. For each parameter measured in each segment the following conditions are listed:

- Parameter name (PAM)
- Desired value (DSRD)
- The transform performed (XFM) on the parameter, i.e. root mean square (RMS), standard deviation (SDEV), etc.
- The raw transformed value (RAW)
- The weighting factor (WF) applied to the RAW value
- The parameter weighted value (WEIGHTED)
- Parameter type - System (S) or Control (C)

```
NAME  TEST001   DATE  06/04/76

FLIGHT 0001   VEH 0001   RUN 0013   ENTRY 0005   LEVELS 0006   CURRENT 0005
MANEUVER: BEAM ATTACK          CG: AFT      TURBULENCE: NONE

           ALTITUDE   AIRSPEED   HEADING    CLIMB RATE  TURN RATE  YAW ANGLE  ANGLE/ATTACK  ROLL ANGLE  ROLL RATE
           (FEET)     (KNOTS)    (DEGREES)  (FT/MIN)    (DEG/SEC)  (DEGREES)  (UNITS)       (DEGREES)   (DEG/SEC)
ASSIGNED   15000      500.0      300.0
ENTRY      [illegible] [illegible] 300.501  -535.662    0.078      -0.369     5.394         3.602       1.189

SEGMENT   0001
   SEGMENT SCORES    SYSTEM   NONE        CONTROL NONE         PROCEDURE 0001     TIME   14.949 SECONDS

SEGMENT   0002
   PAM       DSRD          XFM          RAW         WF        WEIGHTED   TYPE
   ROLL      -30.0         RMS          10.607      10.0      106.070    S
   A/S       500.0         RMS          3.294       5.0       16.472     S
   ALT       15000.0       RMS          30.158      0.250     7.539      S
   BETA      0             RMS          0.498       50.0      24.938     S
   ELVS      0             SDEV         0.225       10.0      2.254      C
   AILS      0             SDEV         0.372       10.0      3.726      C
   SEGMENT SCORES    SYSTEM   38.755      CONTROL   2.990      PROCEDURE 0001     TIME   40.149 SECONDS

SEGMENT   0003
   PAM       DSRD          XFM          RAW         WF        WEIGHTED   TYPE
   HEAD      270.0         RMS          0.974       5.0       4.872      S
   A/S       500.0         RMS          2.438       5.0       12.192     S
   ALT       15000.0       RMS          27.000      0.250     6.750      S
   BETA      0             RMS          0.385       50.0      19.279     S
   ELVS      0             SDEV         0.144       10.0      1.443      C
   AILS      0             SDEV         0.064       10.0      0.644      C
   SEGMENT SCORES    SYSTEM   10.773      CONTROL   1.043      PROCEDURE NONE     TIME   22.399 SECONDS

SEGMENT   0004
   PAM       DSRD          XFM          RAW         WF        WEIGHTED   TYPE
   TURN      -2.0          RMS          1.083       50.0      54.176     S
   A/S       500.0         RMS          3.558       5.0       17.793     S
   ALT       15000.0       RMS          46.511      0.250     11.627     S
   BETA      0             RMS          0.640       50.0      32.046     S
   ELVS      0             SDEV         0.468       10.0      4.680      C
   AILS      0             SDEV         0.749       10.0      7.493      C
   SEGMENT SCORES    SYSTEM   28.911      CONTROL   6.087      PROCEDURE 0001     TIME   24.199 SECONDS
```

Figure 34. Sample student record-beam attack

SEGMENT 0002

RAM	DSRD	XFM	RAW	WF	WEIGHTED	TYPE
A/S	500.0	RMS	5.915	5.0	29.575	S
ALT	15000.0	RMS	37.619	0.250	9.404	S
BETA	0	RMS	0.398	50.0	19.935	S
ELVS	0	SDEV	0.410	10.0	4.102	C
AILS	0	SDEV	0.679	10.0	6.791	C

SEGMENT SCORES SYSTEM 19.638 CONTROL 5.447 PROCEDURE NONE TIME 13.095 SECONDS

SEGMENT 0003

RAM	DSRD	XFM	RAW	WF	WEIGHTED	TYPE
A/S	[illegible]	RMS	16.363	5.0	81.819	S
ALT	15000.0	RMS	273.207	0.250	68.301	S
BETA	0	RMS	0.925	50.0	46.254	S
ELVS	0	SDEV	1.118	10.0	11.184	C
AILS	0	SDEV	1.212	10.0	12.120	C

SEGMENT SCORES SYSTEM 65.458 CONTROL 11.652 PROCEDURE 0001 TIME 5.0 SECONDS

SEGMENT 0010

RAM	DSRD	XFM	RAW	WF	WEIGHTED	TYPE
A/S	500.0	RMS	18.404	5.0	92.024	S
ALT	15000.0	RMS	422.247	0.250	105.561	S
BETA	0	RMS	1.349	50.0	67.460	S
ELVS	0	SDEV	0.154	10.0	1.548	C
AILS	0	SDEV	0.528	10.0	5.287	C

SEGMENT SCORES SYSTEM 88.348 CONTROL 3.418 PROCEDURE 0000 TIME 1.149 SECONDS

FINAL [illegible] 481.913 3.454 1087.844 0.662 -0.877 5.034 36.437 13.159

RUN TERMINATED BY NO RADAR LOCK-ON

GATE-PENETRATION DATA:
X-DISTANCE 1.17 MI Y-DISTANCE 0.31 MI Z-DISTANCE -23 FT
LOOK-ANGLE 4 DEG HEADING 340 DEG AIRSPEED 493 KTS

LOST RADAR LOCK-ON DATA:
X-DISTANCE 0.74 MI Y-DISTANCE 0.00 MI Z-DISTANCE -414 FT
LOOK-ANGLE -3 DEG HEADING 3 DEG AIRSPEED 481 KTS

MANEUVER FINAL SCORES: SYSTEM 46.028 CONTROL 4.792 PROCEDURE 8.333
RUN TIME 186 SECONDS TOTAL RUNS THIS FILE 0001 95 PERCENT RUN ADJUSTMENT
MANEUVER WEIGHTING FACTOR = 1.0
ADAPTIVE LOGIC INCREMENT = 0

. . . .

Figure 34. (cont.) Sample student record-beam attack

The last line of each segment listing contains the segment's system, control and procedures scores plus the time it took the student to complete the segment.

The line following the last segment printout lists the final parameters for the trial, i.e., Altitude, Heading, Airspeed, etc. The next line prints the reason for termination of the trial.

If, as in this case, the trial was an air-to-air maneuver, target acquisition and firing/lost lock-on data are printed as follows:

- The X,Y and Z distance coordinates as compared to the target vector.
- The interceptor look-angle, heading and airspeed at occurance of these events.

These data are omitted in a non-air-to-air maneuver.

The next line contains the maneuver final scores for the system, control and procedure categories. The next two lines list the total run time, the number of runs now in the file, the run adjustment factor (actual run time/ nominal run time) and the maneuver weighting factor. The final line provides the adaptive logic increment for selection of the next trial.

APPENDIX E
OPERATING PROCEDURES

START-UP PROCEDURE

a. Initial Conditions

1. Sigma-7 computer and peripherals ON and operating normally.

2. Ensure following circuit breakers at the Circuit Breaker Panel are OFF:

   (a) G-Rack

   (b) CMC

   (c) Power Supply

3. Place Sigma-7 computer in IDLE mode.

4. Insert F-4 Simulator Panel into Central Patchboard.

5. Turn the following circuit breakers ON at the Circuit Breaker Panel:

   (a) G-Rack

   (b) CMC

   (c) Power Supply

6. Ensure all the buttons at the Monitor Console are RESET (out), except the following which should be SET (in):

   (a) Reset-to-Zero

   (b) γ Roll

   (c) γ Pitch

   (d) γ Yaw

7. Mount Student Record Tape on MTU 7. Depress START button.

b. COGNITRONICS[1]

1. Turn both switches at the COGNITRONICS Panel to ON.

2. Adjust COGNITRONICS speaker volume control at the rear of the Monitor Console.

[1]Trademark

c. Loading the F-4/BIFM Program from magnetic tape

1. Set all Sigma-7 System Sense switches to Ø (zero).

2. Ensure the WRITE PROTECT switches for Disc OF1 are RESET (down position).

3. Boot F-4/BIFM Program Binary Tape onto Disc OF1 (standard Sigma-7 operating procedure).

4. Load F-4/BIFM program from Disc OF1 in Sigma-7 memory (standard Sigma-7 operating procedure).

5. Depress the RUN button on Sigma-7 Supervisory Console (F-4/BIFM Program is now running).

d. IDIIOM Display

1. Energize the IDIIOM and VARIAN 620/I computer (standard IDIIOM procedure).

2. Load paper tape containing the BIFM Display List/Sigma-7 Communications Programs (standard IDIIOM loading procedure).

3. Place IDIIOM in STEP mode. Reset all IDIIOM Registers.

4. Turn the following Sigma-7/IDIIOM Interface Switches to ON:

   (a) POWER

   (b) ON-LINE

5. Place 1000_8 in P-Register (Display program starts at location 1000_8).

6. Depress SYSTEM RESET Switch, then RUN switch (Display program is now running and ready for Sigma-7 communications).

7. Adjust THRESHOLD and INTENSITY knobs at main and remote displays for best picture.

e. F-4 Trainee Subject Preparation

1. If this is first session, present subject with BIFM PRELIMINARY BRIEFING prior to subject entering cockpit.

2. While briefing is being presented, depress the RESET-TO-ZERO button on the Monitor Console and input STUDENT FILE DATA (refer to Student File Inputs presented later in this section).

3. After BIFM PRELIMINARY BRIEFING, the subject will enter the cockpit and conduct the Pre-flight Check.

4. Energize the Motion System (use standard procedure).

5. When subject is ready, release the RESET-TO-ZERO button on the Monitor Console. At this point the program becomes fully automatic until completion of the Exercise Session.

   NOTE: If at any time it is desired to terminate the session, it may be accomplished by again depressing the RESET-TO-ZERO button on the Monitor Console.

BIFM EXERCISE OPERATIONS

a. The BIFM program is fully automatic and operator intervention should be held to a minimum. Operator intervention, if required, may be accomplished via the controls at the Monitor Console.

   NOTE: The following controls are inactive since they are overridden by the BIFM program.

   1. ROUGH AIR INPUT

   2. FUEL INCR/DECR INPUT

   3. CENTER TANK ON/OFF INPUT

   4. WING TANKS ON/OFF INPUT

SHUT-DOWN PROCEDURE

a. Subject Egress

   1. Turn off motion system using standard procedure.

   2. Have subject perform Post-Flight Check.

3. When platform levels and locks, allow subject to leave cockpit.

4. If a new subject is scheduled, re-start. (See START-UP Procedure).

b. Program Shut-Down

1. Depress sense switch #1 on the Sigma-7 Supervisory Console and allow F-4 program to "run down".

2. After program stops, place Sigma-7 computer in IDLE mode.

c. Generalized Control Station Shutdown

1. Depress the I/O RESET button on Sigma-7 Supervisory Console.

2. Turn the following switches at the Circuit Breaker Panel to OFF:

   (a) G-Rack Switch

   (b) CMC Switch

   (c) Power Supply Switch

3. Remove F-4 Simulator Panel from Central Patchboard.

d. COGNITRONICS

1. Turn both switches at the COGNITRONICS Panel to OFF.

e. IDIIOM Display

1. Turn THRESHOLD and INTENSITY knobs down at main and remote displays.

2. Turn following Sigma-7 IDIIOM Interface Switches to OFF:

   (a) ON-LINE

   (b) POWER

3. Place IDIIOM in STEP mode.

4. Follow standard IDIIOM shut-down procedure if no further IDIIOM programs are to be run.

f. Dismount and Save Student Record Tape on MTU7.

STUDENT FILE INPUT PROCEDURES

a. Student name entry: \$FILE NAME$^{n}_{1}$. Normal order of input can only be accomplished when the RESET TO ZERO button on the Monitor Console is depressed. Whenever this button is depressed, the keyboard printer responds with:

INPUT STUDENT FILE DATA

NAME can be up to eight characters. Blanks are ignored. Up to twenty files can be maintained. ($^{n}_{1}$ in all examples indicates "new line" key.)

If a new file (name not already in file), the exercise is automatically set to the first exercise, at the entry difficulty level. The session number and run number are set to 1; and the total number of runs for this file is set to Ø.

Example:

Keyboard Input:

\$FILE SMITH$^{n}_{1}$

NOTE: Before any keyboard input can be made, the lamp on the keyboard must be illuminated. This is accomplished by depressing the INTERRUPT button on the Sigma-7 System Console.

Typewriter Response:

NEW FILE

NAME	SMITH	DATE	/ / /
EXER	BIM	LEVEL	01/5/8/5
SESS	0001	RUN	0001
TOTAL RUNS THIS FILE			0000

If an old file (name already in file), the date, exercise, level session number, run number, and total runs are retrieved from the file and printed each time an existing file is requested. The session number is automatically incremented by 1. Run number indicates the next run for this session and is reset to 1 each time the session number is advanced.

Example:

Keyboard Input:

`$FILE JONES`$^{n}_{1}$

Typewriter Response:

OLD FILE

NAME	JONES	DATE	08/01/76
EXER	BIM	LEVEL	09/5/8/3
SESS	0002	RUN	0001
TOTAL RUNS THIS FILE			0014

b. Date Entry: `$DATE XX/XX/XX`$^{n}_{1}$. The date may be inserted or updated by this command. Input is constrained to a rigid format in that two numbers separated by a slash (/) must be supplied for the month, day and year.

Example: October 1, 1976

Keyboard Input:

`$DATE 10/01/76`$^{n}_{1}$

Typewriter Response

NAME	JONES	DATE	10/01/76
EXER	BIM	LEVEL	01/5/8/3
SESS	0001	RUN	0003
TOTAL RUNS THIS FILE			0002

d. Exercise control override: `$EXER SUB=XX/E/N/C`
or
`$EXER BIM=XX/E/N/C`

The exercise and difficulty level set by the Adaptive Logic Program can be overridden by this command.

SUB and BIM are the three letter exercise designators (SUB for subsyllabus and BIM for Basic Instrument Flight maneuvers) and

XX - Maneuver Index
E - Entry Level = 5   C = Current Level
N - # of Levels = 8 $1 \leq C \leq N$

Example:

Keyboard Input:

$EXER BIM = 01/5/8/7

Typewriter Response:

NAME	SMITH	DATE	10/01/76
EXER	BIM	LEVEL	01/5/8/7
SESS	0001	RUN	0001
TOTAL RUNS THIS FILE			0000

c. Run Change: \$RNUM N_1^n. The current run number may be changed by this command.

Example:

Keyboard Input:

\$RNUM 1_1^n

Typewriter Response:

NAME	SMITH	DATE	10/01/76
EXER	BIM	LEVEL	01/5/8/7
SESS	0001	RUN	0001
TOTAL RUNS THIS FILE			0000

d. Session Change: \$SNUM N_1^n. Similar to \$RNUM M in that that session number is updated in the current file, e.g. \$SNUM 15

e. Total Run Change: \$TNUM N_1^n. Similar to \$RNUM in that the number of total runs in the current file is updated, e.g. \$TNUM 25.

f. Delete Name: $DELE NAME $^n_1$ Deletes the file indicated by "NAME" and reinitializes it for future use by new students (normally delete is used after the student has completed the curriculum).

Example:

Keyboard Response:

FOLLOWING FILE DELETED:

NAME	HUNTLEY	DATE	10/01/76
EXER	BIM	LEVEL	15/5/8/8
SESS	0004	RUN	0005
TOTAL RUNS THIS FILE			0100

g. Start Exercise: GO^n_1$ This is a mandatory command used to start the indicated session after all the necessary STUDENT FILE DATA has been input. No further STUDENT FILE DATA will be accepted until the RESET-TO-ZERO button is again depressed.

Example:

GO^n_1$

Typewriter Response:

START EXERCISE

ABSOLUTE PROGRAM PATCHES

Two commands allow the printing or modification of any memory location in the F-4/BIFM program. They should be used, therefore, with caution so that inadvertent program anomalies are not introduced. Absolute Program Patch commands are identified by the character, + (plus).

a. Memory Location Printing

One memory location may be typed out using the following format:

+PRTLLLL$^n_1$

where: LLLL is a 4-digit hexadecimal memory location. Leading zeros must be included for memory locations less than 4 digits. The typewriter will respond with the 8-digit hexadecimal contents of location LLLL.

Example:

Keyboard Input:

+PRT 03F9$^{n}_{l}$

Typewriter Response:

FIF6F2F3

which indicates memory location 03F9 contains the hexadecimal number FlF6F2F3.

b. Memory Location Modification

One memory location may be modified using the following format:

+MOD LLLL, MMMMMMMM$^{n}_{l}$

where: LLLL is a 4-digit hexadecimal memory location which is to be modified with the value MMMMMMMM. Leading zeros must be included if LLLL is less than 4 digits or MMMMMMMM is less than 8 digits.

If the value is accepted, no typewriter response will be given. If the input is in error, the typewriter will respond with:

"ILLEGAL INPUT FORMAT"

Examples:

Keyboard Input:

+MOD 12C5, 6AF00834$^{n}_{l}$

Typewriter Response: None

Keyboard Input:

+MOD 1A6l, F0FlF2F$^{n}_{l}$

Typewriter Response: ILLEGAL INPUT FORMAT (only 7 characters for modification value)

APPENDIX F

AIR-TO-AIR ATTACK CONTROLLER MODEL

GENERAL

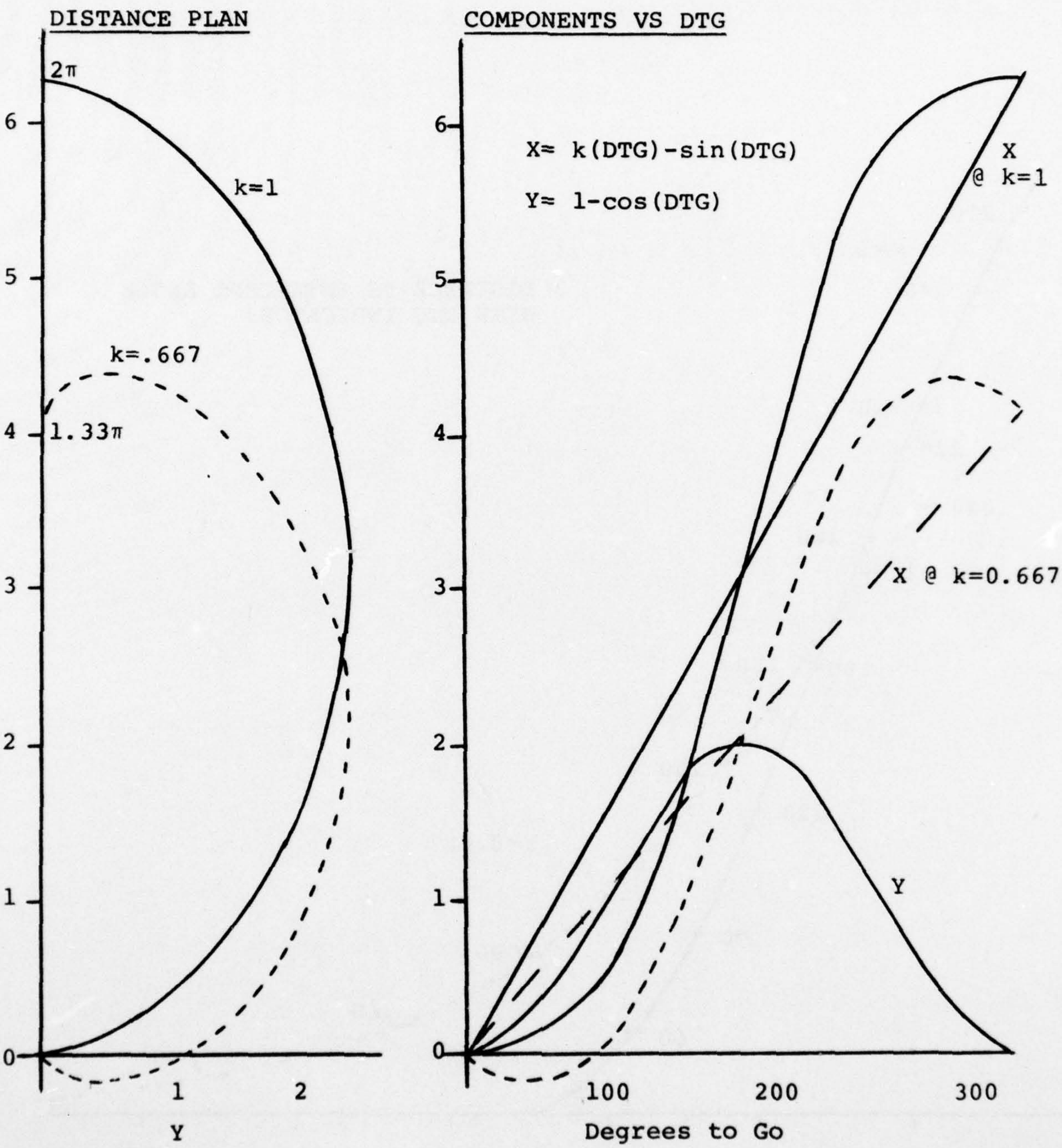
The basic Air-to-Air Attack Controller Model developed for Appli-Mation by Mr. Steve Barnaby of Canyon Research Group, Inc. is presented in this Appendix.

DESCRIPTIVE GEOMETRY

Contained within the intercept problem are several important factors. These include the constant turn rate of the interceptor, the speed advantage of the interceptor and the location of the intercept point (aft of the target). The first defines the characteristics of the intercept geometry while the latter two create complications in the descriptive geometry. For the purpose of the analysis, the concept of an intercept point is used vs the target position. The intercept point is defined as that point which is astern of the target at which the interceptor's heading is identical to that of the target's. By using this point as the reference, the geometry becomes independent of the turn rate as that variable can be included within the calculation of the radius. The equation for the radius becomes:

$$D = 2R = 0.63662\ V_i\ (180/TR)$$

The use of this simplification allows the measure of distance in units of radius thus providing a generalized geometry profile. The path profile of the intercept is illustrated in Figure 35. When the target and interceptor have identical speed (ie; $k = 1 = V_t/V_i$), the path profile is a cycloid. The point of symmetry resides at pi*R in the X axis. With speed advantage, the profile alters significantly with the limit being a circle (ie; $V_t/V_i \rightarrow 0$). The velocity profile in all cases is circular which is shifted below the X axis equal to k. Two plots of control parameters have been computed and calculated. One is a plot of the direction vector (magnitude vs angle) which is illustrated in Figure 36. The other is a plot of closure rate vs distance which is illustrated in Figure 37. Both of these are common in control guidance. Table 20 lists the distance data and Table 21 the velocity data for the plots.



$X = k \cos^{-1}(1-y) \pm (2y-y^2)^{\frac{1}{2}}$

$Y = V_t/V_I = 1$ @ Same Speed
$= .667$ @ 4/6 Speed Advantage

Figure 35. Distance Geometry

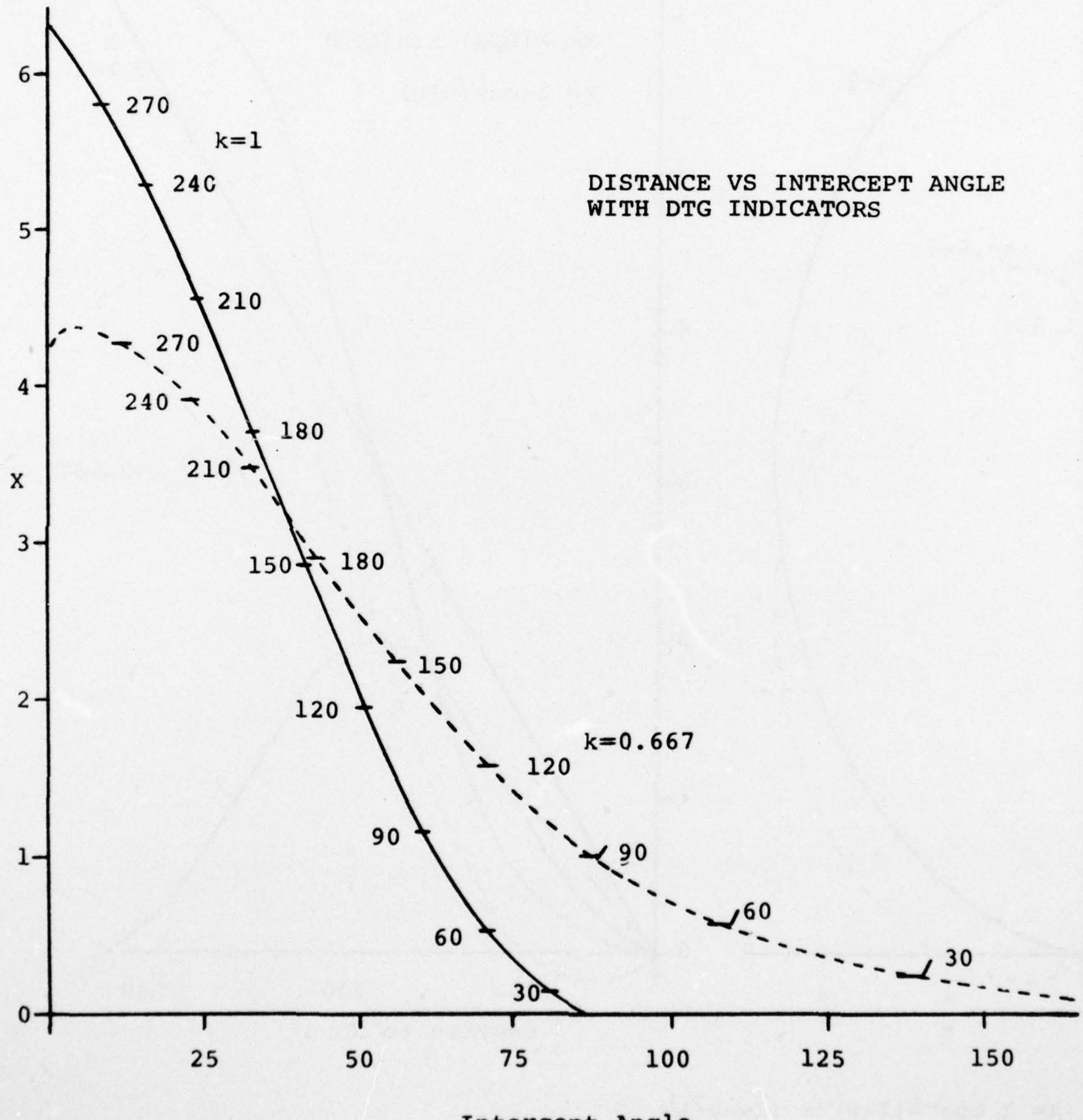


Figure 36. Distance versus Intercept Angle

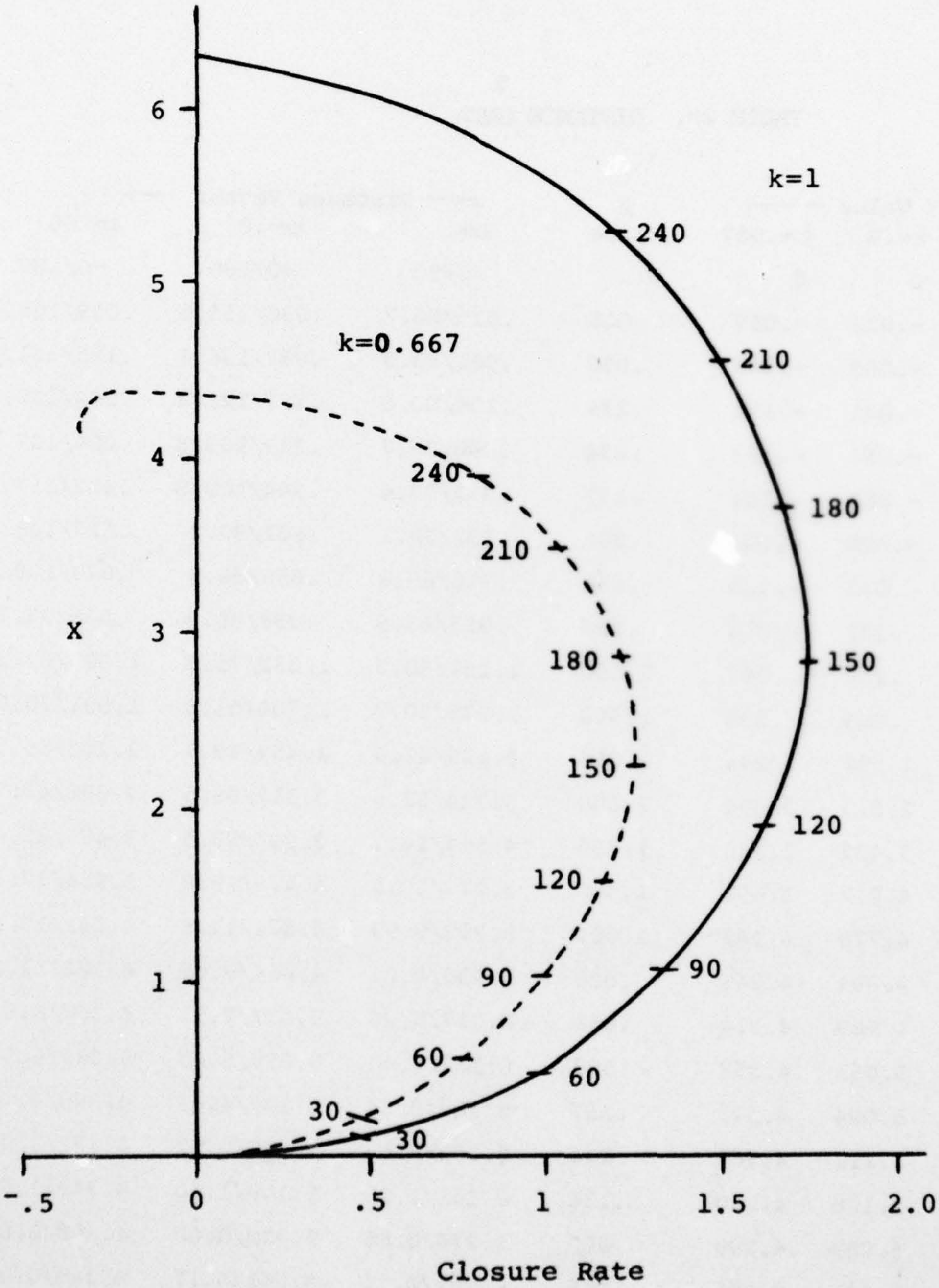


Figure 37. Closure Rate versus Distance

TABLE 20. DISTANCE DATA

DTG	X Value k=1	X Value k=.8	X Value k=.667	y Value	Distance Vector k=1	Distance Vector k=.8	Distance Vector k=.667
0	0	0	0	0	+0/90	+0/180	+0/180
10	.001	-.033	-.057	.015	.015/86.7	.036/155.6	.059/165.3
20	.007	-.063	-.109	.060	.061/83.3	.087/136.1	.125/151.1
30	.024	-.081	-.151	.134	.136/80.0	.157/121.2	.202/138.4
40	.055	-.084	-.177	.234	.240/76.7	.249/109.8	.294/127.2
50	.107	-.068	-.184	.357	.372/73.4	.364/100.8	.402/117.3
60	.181	-.028	-.168	.500	.532/70.1	.501/93.2	.527/108.6
70	.282	.038	-.125	.658	.716/66.8	.659/86.7	.670/100.8
80	.411	.132	-.054	.826	.923/63.5	.837/80.9	.828/93.7
90	.571	.257	.047	1.000	1.151/60.3	1.032/75.6	1.001/87.3
120	1.228	.809	.530	1.500	1.939/50.7	1.704/61.6	1.591/70.5
150	2.118	1.594	1.245	1.866	2.823/41.4	2.454/49.5	2.243/56.3
180	3.142	2.513	2.094	2.000	3.724/32.5	3.212/38.5	2.896/43.7
210	4.165	3.432	2.943	1.866	4.564/24.1	3.907/28.5	3.485/32.4
240	5.055	4.217	3.659	1.500	5.273/16.5	4.476/19.6	3.954/22.3
270	5.712	4.770	4.142	1.000	5.799/9.93	4.874/11.8	4.261/13.6
280	5.872	4.894	4.243	.826	5.930/8.01	4.964/9.58	4.322/11.0
290	6.001	4.989	4.314	.658	6.037/6.26	5.032/7.51	4.364/8.67
300	6.102	5.055	4.357	.500	6.122/4.68	5.079/5.65	4.385/6.55
310	6.177	5.094	4.373	.357	6.187/3.31	5.107/4.01	4.388/4.67
320	6.228	5.111	4.366	.234	6.232/2.15	5.116/2.62	4.372/3.07
330	6.260	5.108	4.340	.134	6.261/1.23	5.109/1.50	4.342/1.77
340	6.276	5.089	4.298	.060	6.276/0.55	5.090/0.68	4.298/0.80
350	6.282	5.061	4.246	.015	6.282/0.14	5.061/0.17	4.246/0.21
360	6.283	5.027	4.189	0	6.283/0.00	5.027/0.00	4.189/0.00

TABLE 21. VELOCITY DATA

DTG	Velocity Vector k=1	Velocity Vector k=.8	Velocity Vector k=.667	Closure Velocity k=1	Closure Velocity k=.8	Closure Velocity k=.667
0	0.000/90	.200/180	.330/180	0	.200	.333
10	.174/85	.254/136.8	.362/155.4	.174	.240	.357
20	.347/80	.369/112.2	.438/128.6	.346	.337	.405
30	.518/75	.504/97.5	.538/111.7	.516	.461	.481
40	.684/70	.644/87.0	.650/98.8	.679	.594	.572
50	.845/65	.782/78.4	.766/88.2	.836	.723	.669
60	1.000/60	.917/70.9	.882/79.1	.985	.848	.768
70	1.147/55	1.045/64.0	.994/70.9	1.123	.964	.862
80	1.286/50	1.167/57.5	1.101/63.4	1.250	1.071	.951
90	1.414/45	1.281/51.3	1.202/56.3	1.364	1.168	1.030
120	1.732/30	1.562/33.7	1.453/33.6	1.620	1.380	1.162
150	1.932/15	1.739/16.7	1.612/18.1	1.731	1.462	1.267
180	2.000/0	1.800/0	1.667/0	1.687	1.409	1.205
210	1.932/-15	1.739/-16.7	1.612/-18.1	1.499	1.143	1.025
240	1.732/-30	1.562/-33.7	1.453/-33.6	1.192	.933	0.815
270	1.414/-45	1.281/-51.3	1.202/-56.3	.812	.786	0.414
280	1.286/-50	1.167/-57.5	1.101/-63.4	.681	.454	-.296
290	1.147/-55	1.045/-64.0	.994/-70.9	.552	.331	.180
300	1.000/-60	.917/-70.9	.882/-79.1	.428	.213	.067
310	.845/-65	.782/-78.4	.766/-88.2	.312	.103	-.038
320	.684/-70	.644/-87.0	.650/-98.8	.210	.004	-.133
330	.518/-75	.504/-97.5	.538/-111.7	.123	-.092	-.214
340	.347/-80	.369/-112.2	.438/-128.6	.057	-.143	-.278
350	.174/-85	.254/-136.8	.362/-155.4	.015	-.186	-.330
360	0.000/-90	.200/-180	.330/-180	0	-.200	-.333

INTERCEPT MODEL

Either indication of path profile can be used for guidance and control. Math models of both have been derived during this effort. Both are accurate and both are effective to 10 DTG by which time rollout is expected to be underway. The model for the distance vector method is slightly more accurate than the model involving closure rate; however, the latter control model is similar to the Air Force approach to the intercept problem.

Distance Vector Model. The profile desired in this model was previously presented in Figure 36. The profile maintains essentially a straight line between 120 and 240 DTG. The slope of the straight line is dependent upon k (speed advantage). Below 120 DTG, the slope softens to zero at the angle axis intercept. The decay rate of the slope is k dependent. Simulation greater than 240 DTG, while of marginal value, can be modeled by the continuation of the straight line until a k dependent limit is reached. The best fit model is contained in Figure 38. Its accuracy per data point is generally better than 2%.

The concept of this model is based upon the relative angle of the interceptor from the intercept point. Knowing this value, one applies the equation to determine the value X (i.e.; the number of radii). The radius equation is then used to relate the X value, the actual range and the turn rate. By use of the three parameters, both the entry and guidance information can be obtained. Additionally, by use of allowable turn rates, performance measures can be implemented.

Closure Rate Model. The profile desired for this model was previously presented in Figure 37. It is essentially an elliptical path in which the closure rate is bimodal. At high DTG values, the profile path deviates from an elliptical path. However, this occurs above 240 DTG. The deviation from the elliptical path is also k dependent with only minor errors occuring at k equal to 1.

The best fit model is illustrated in Figure 39. Its accuracy per data point is generally better than 6%. The usage can be the same as the previous model with the input parameter being closure rate. However, since it is bimodal, there would be two answers. This can be resolved by noting the existing DTG (i.e.; below 160 DTG accept the smaller X; above 160 accept the larger value). Another way to solve the same model is to solve for the computed closure rate using the actual range and turn rate, find the closure rate error and use the differential of the ellipse equation to determine the delta X or its reciprocal which is delta

GENERAL EQUATIONS:

$$X = MA + b + CA_1{}^P$$

Where:

$M = (-0.1466k + 0.0491)$

$b = 5.533k + 1.37$

$C = 0.0157k - 0.0071$

$A_1 = (A - A_0)$ if plus, else zero

$$A_0 = \frac{(4.483k + 0.492)}{(0.1466k - 0.0491)}$$

$P = 1.5$

$A =$ Actual Angle

$k =$ Speed Ratio $= \dfrac{\text{Target Speed}}{\text{Interceptor Speed}}$

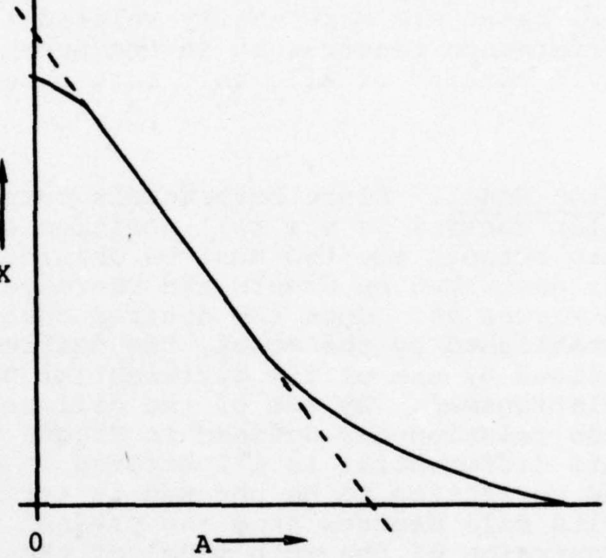


Figure 38. Distance Vector Model

PATH EQUATIONS:

$$CR = \frac{CR_G}{X_G}\,(2X_GX - X^2)^{1/2}$$

Where:

$CR_G = 1.41k + 0.333$

$X_G = 2.54k + 0.59$

or

$$X = X_G \pm X_G\,[CR_G{}^2 - CR^2]^{1/2}$$

DIFFERENTIAL

$$dX = \left[2(2X_GX - X^2)^{1/2} / (CR_G/X_G)(2X_G - 2X)\right] dCR$$

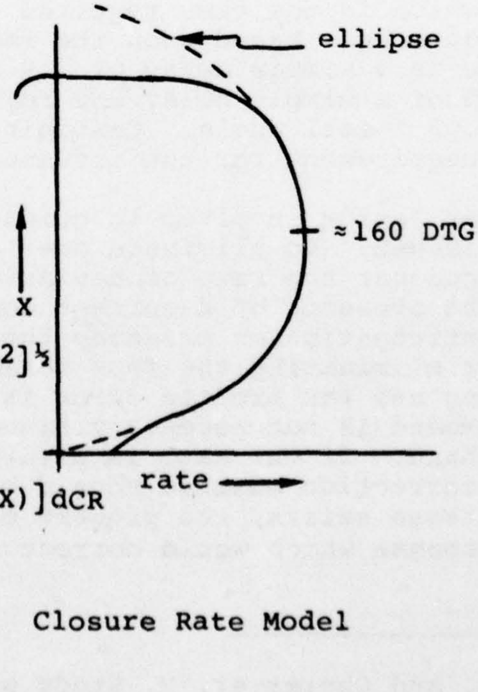


Figure 39. Closure Rate Model

turn rate. By this latter approach, guidance can be paraphrased in terms of turn rates instead of closure rates since turn rates are more easily related to pilot input commands. Performance measures as in the previously described model could consist of allowable turn rates.

Pilot Model. Since both models output turn rate and the pilot control is via roll position commands, the relationship between the two must be obtained. This relationship was described by Vreuls and Obermayer[1] and is illustrated in Figure 40. Once the desired change in turn rate has been established by the model, the desired change in roll can be defined by use of the differential of the roll/turn rate relationship. By use of the differential, the fixed magnitude relationship defined in Figure 40 can be eliminated. This differential is illustrated in Figure 41. This allows the correction to be phrased in terms of adding or subtracting delta roll degrees from the present value and allows a direct conversion of the math model of the profile to the pilots control parameter.

Another factor involving the pilot model is time delays. As pointed out by Vreuls and Obermayer[1], the pilot model exhibits two significant time delays. One is response time which includes the period from the beginning of the message to when he starts the control action. The second time factor is rise time which is the time required to establish the roll command requested. Based upon the results of the study, response time is a simple delay of 0.9 seconds while rise time is composed of a simple delay and roll dependent component of 0.5 + 0.03 * roll angle. Combining these two creates a lead term requirement for the issuance of commands.

Another factor involved in guidance is when commands should be issued. To eliminate over correction, one must take into account the rate of deviation from the desired path and the presence of a current command. If the rate is closing, anticipation of crossing the path profile provides the cue for eliminating the rate term. If the rate term is not changing and the profile error is within tolerance, a closure command is not necessary since he is within the tolerance band. If the rate is diverging without a current command, a correction message should be generated. If a current message exists, the program must look for a recent control response which would correct for the divergence

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[1] Vreuls, D. and Obermayer, R. Study of Crew Performance Measurement for High Performance Aircraft Weapon System Training: Air-to-Air Intercept. NAVTRADECCEN 70-C-0059-1, Manned Systems Sciences, Inc., February 1971.

or else over-control is probable. The concept of a current message should be based upon the time delays presented earlier.

MODEL IMPLEMENTATION

Three types of air-to-air attacks were implemented based upon the closure rate module. These were:

- Beam Attack
- Forward Quarter Attack
- Head-on Attack

The specific intercept discussed below is the beam attack. The forward quarter and head-on attacks are similar in nature to the beam attack except for the initial conditions and the elimination of 30° turn toward the target.

The plan view of the starboard beam attack is shown in Figure 42. The tactically generated profile of the beam convergence intercept is to establish a 90 DTG path at 20 NM which is a collision course (i.e.; Y distance = 5/4 of the X value or maintenance of -128.66 degrees relative angle). At 13 NM, the interceptor turns to 120 DTG until the target crosses its nose (approximately 8 NM). The interceptor then starts the constant turn profile to intercept with the nominal roll angle of 45 degrees. Based upon the descriptive geometry, the actual initiation should occur at 7.48 NM from the intercept point at which time the intercept point bears 1.6 degrees off the nose. The difference indicates that in the tactical description, the interceptor is ahead of the actual requirement by approximately the target lead distance. Substituting the intercept point for the target will accomplish the proper intercept.

Figures 43, 44 and 45 expand upon the plan view of Figure 42. Figure 43 presents the initial constant bearing geometry and equations which corresponds to the "relative line @ $V_I <$ 270" path in Figure 42. Figure 43 illustrates the geometry and equations for the command to the 120 DTG intercept point which are valid for the "relative line @ $V_I < 240$" path in Figure 42. This occurs once the interceptor has turned 30° toward the target to intercept the 120 DTG point. Figure 45 depicts the RIO geometry and equations which occurs once the interceptor reaches the 120 DTG point and continues until the interceptor reaches the "lock-on" position astern of the target.

The forward quarter and head-on attacks are similar to the beam attack except the interceptor is initialized at a range of

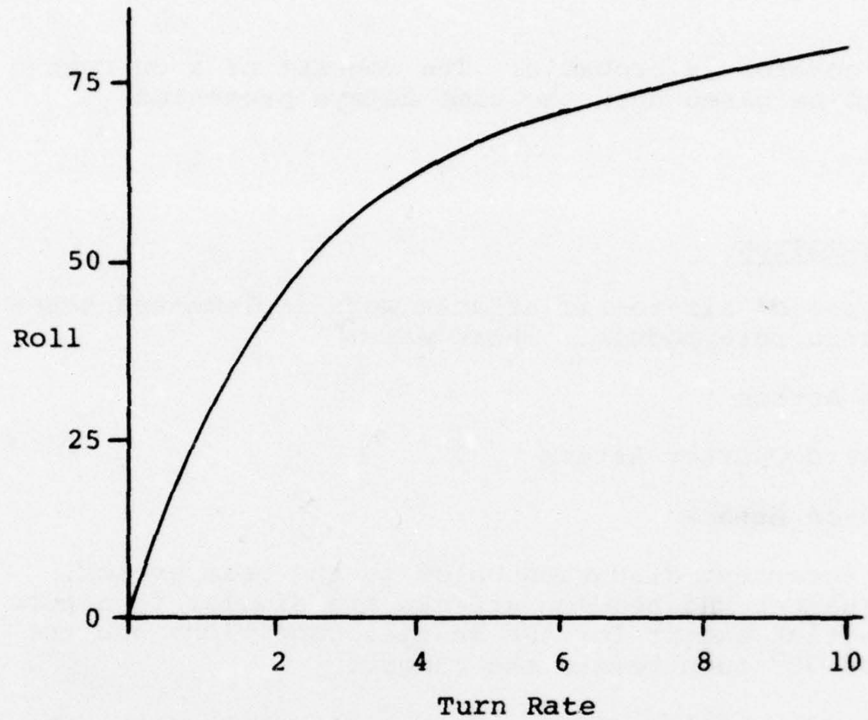

Figure 40. Roll versus Turn Rate

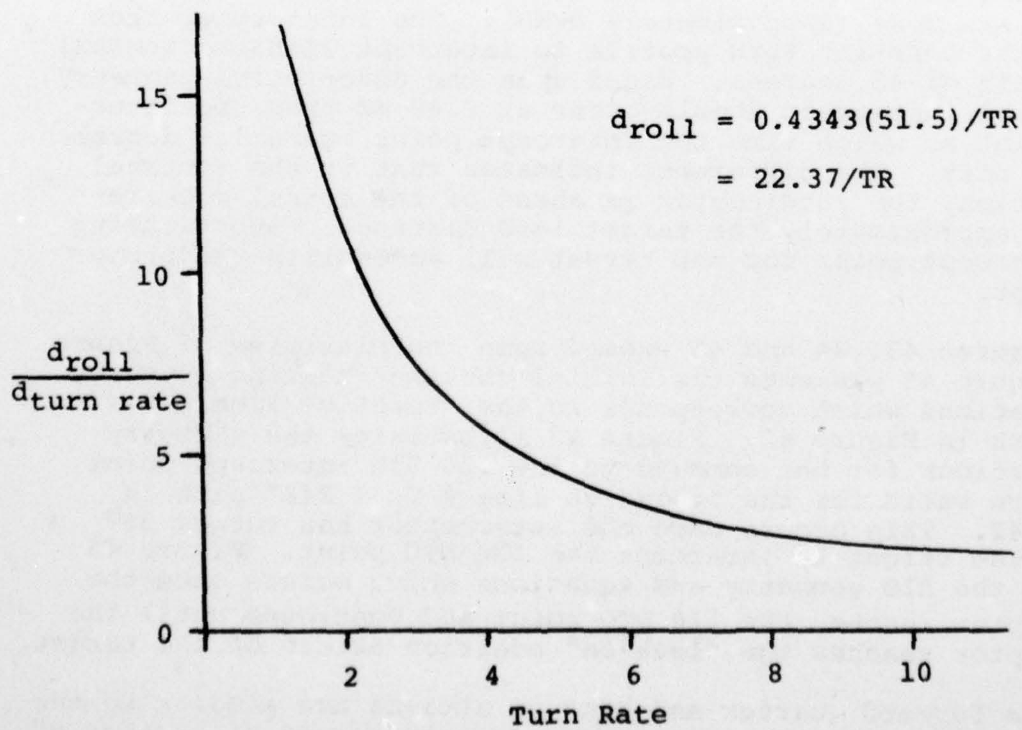

Figure 41. ΔRoll versus Turn Rate

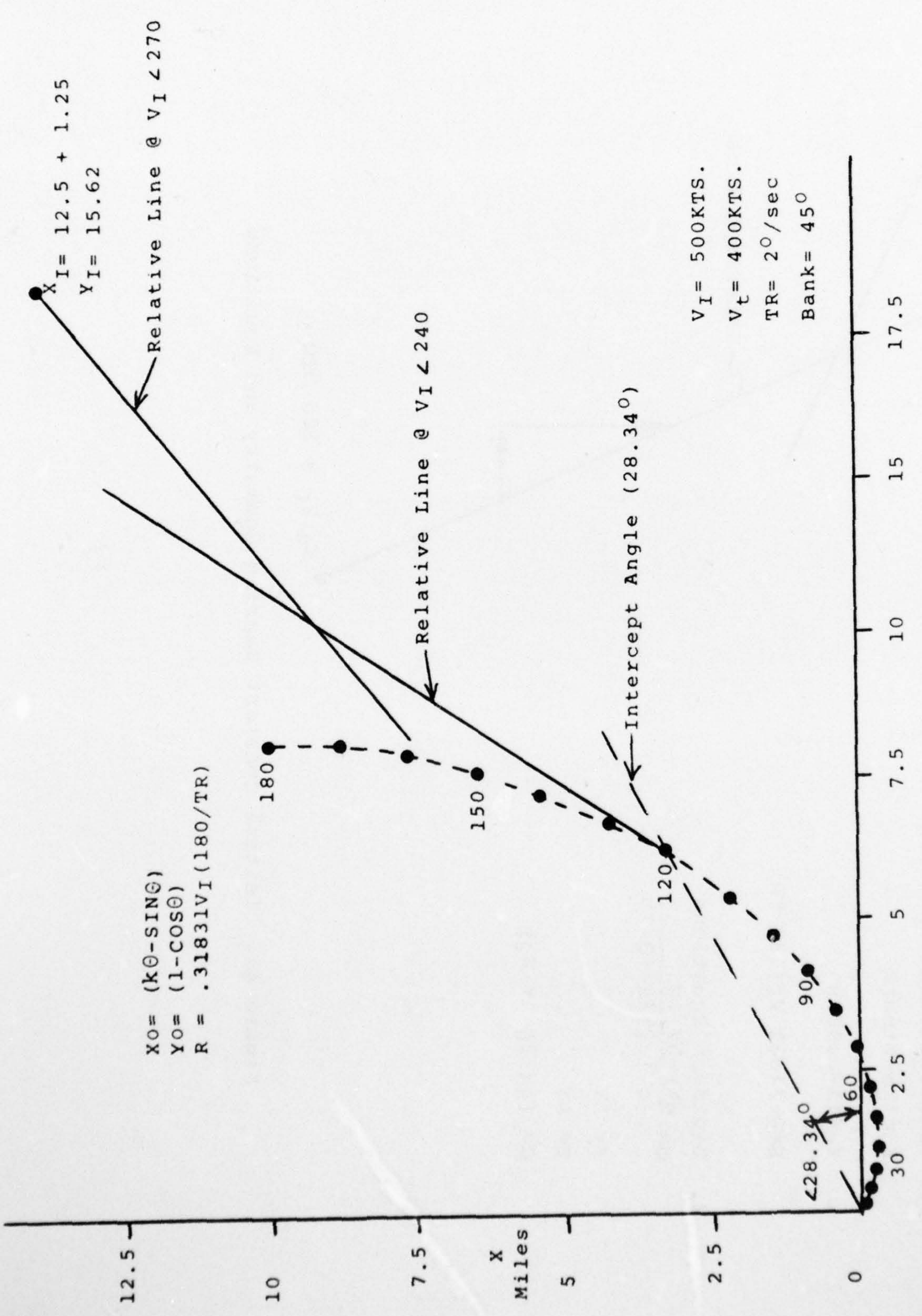

Figure 42. Air-to-Air Intercept Plan View

1. Intercept Line Equations

   $X_0=(k\Theta-\sin\Theta)R$

   $Y_0=(1-\cos\Theta)R$

   $R=0.31831\ V_I(180/TR)$

2. Distance Equations

   $$d=\frac{AX_I-BY_I+C}{(c/|c|)(A^2+B^2)^{\frac{1}{2}}}$$

   $A=\Delta Y$

   $B=\Delta X$

   $C=(\Delta X\cdot Y_0-\Delta Y\cdot X_0)$

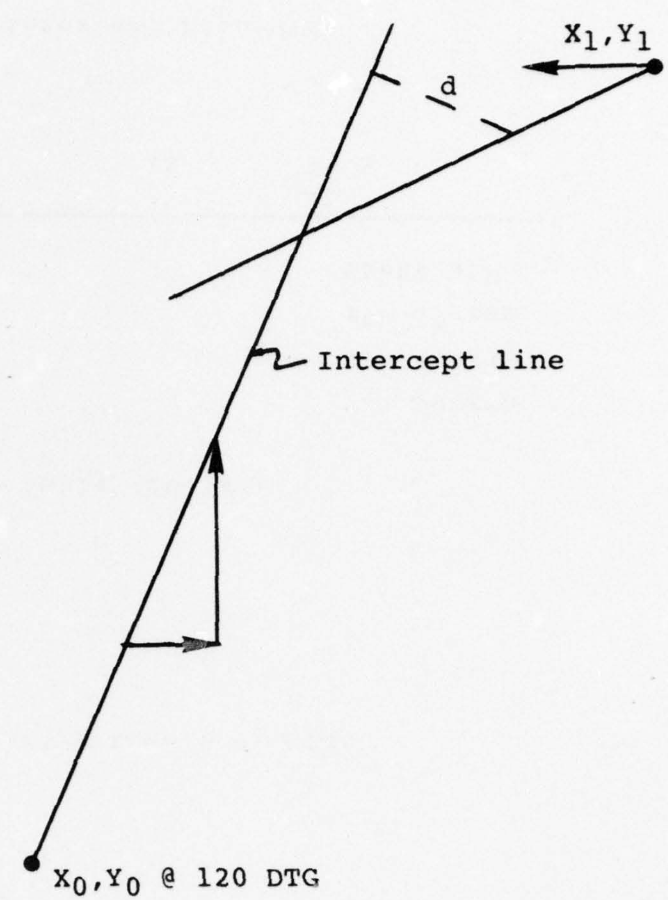

Figure 43. Initial Constant Bearing Geometry and Equations

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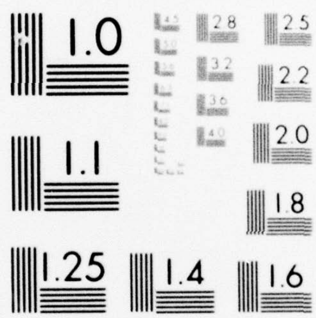

MICROCOPY RESOLUTION TEST CHART
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1. Intercept angle, α

$$\alpha = \mathrm{TAN}^{-1}(X_0/Y_0)$$

2. Displacement Errors

$$d_{err} = \frac{AX_1 - BY_1 + C}{(c/|c|)(A^2+B^2)^{1/2}}$$

$$\Psi_{err} = \frac{d_{err}}{\left[(X_0-X_1)^2 + (Y_0-Y_1)^2\right]^{1/2}}$$

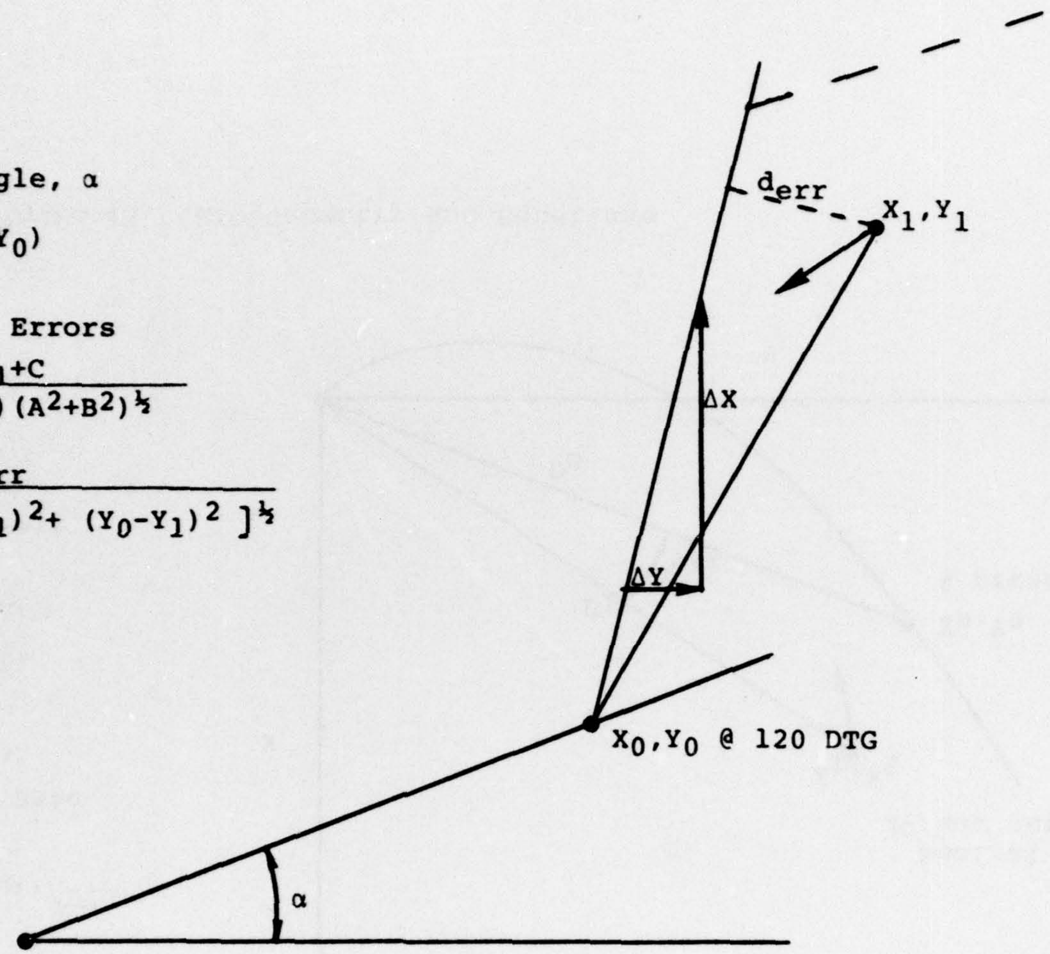

Figure 44 . Command to 120 DTG Intercept Point Geometry and Equations

1. Angular Displacement Error, α_{err}

   $\alpha_{err} = \mathrm{TAN}^{-1}\ (X_1/Y_1) - \mathrm{TAN}^{-1}\ (X_0/Y_0)$

2. Turn Rate Desired, TR_D

   $TR_D = TR_N\ (D_0/D_1)\ (1+(\alpha_{err}/DTG)$

   Where:

   TR_N = Nominal Turn Rate

   DTG = Degrees-To-Go

3. Desired Roll Angle, d_{roll}

   $d_{roll} = 11.185\ (TR_D - TR_A)$

   Where:

   TR_A = Actual Turn Rate

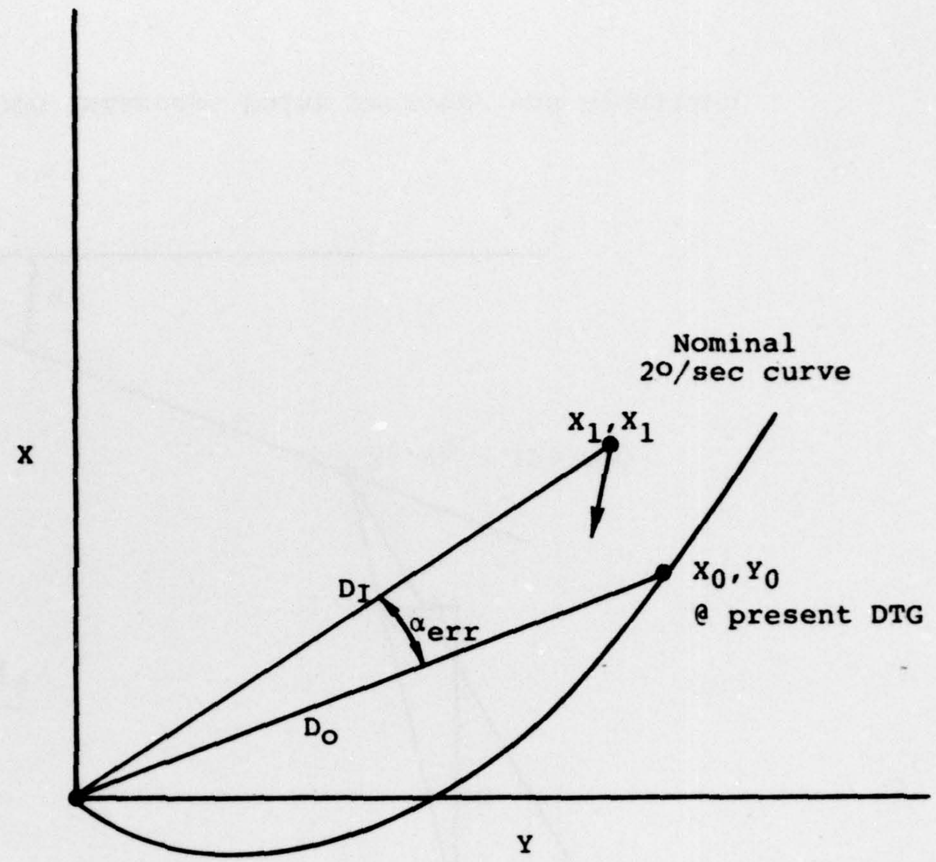

Figure 45. RIO Geometry and Equations

20 NM from the target at a bearing and on a course to intercept the 150 DTG and 180 DTG points respectively. Once the appropriate DTG point is reached the same geometry and equations listed in Figure 45 apply.

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

TERMS	
ACM	Air Combat Maneuvering
ACT	Air Training Command
AF	Final Attack Score
AFB	Air Force Base
AFHRL	Air Force Human Resources Laboratory
AFT	Automatic Flight Training
AILS	Aileron Input
ALT	Altitude
AN	Airways Navigation
AOA	Angle of Attack
A/S	Air Speed
ATE	Automatic Training Evaluation
BETA	Side Slip Angle
BI	Basic Instruments
BIFM	Basic Instrument Flight Maneuver
BIM	Basic Instrument Maneuver
CBT	Constant Bank Turns
C/D, C&D	Climb(s) and Dive(s)
CDT	Climbing and Diving Turns
CG	Center of Gravity
C/T	Configuration/Turbulence Difficulty Levels
CIC	Combat Information Center
CNATRA	Chief of Naval Air Training
CONF	Configuration
Cma	Control Score for maneuver a

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS (cont.)

TERMS	
CQ	Carrier Qualification
Csn	Control Score for segment n
D/C	Dive/Climb
Decr	Decrease
DTG	Degrees to go
Deg	Degrees
DSRD	Desired
e	Elapsed
ELVS	Elevator Input
E&S	Evans and Sutherland Display
EXER	Exercise
F	Formation
FAF	Final Approach Fix
FAM	Familiarization
fpm, ft/min	Feet per minute
ft	Feet
G	Acceleration
GCA	Ground Controlled Approach
GCAM	Ground Controlled Approach Module
GCI	Ground Controlled Intercept
GUN	Gunnery
IAF	Initial Approach Fix
IAS	Indicated Air Speed

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS (cont.)

TERMS	
ID	Identification Data
IP	Instructor Pilot, Initial Point
Incr	Increase
INV	Inverted Flight
k	Target/Interceptor Speed Ratio
K	Number of Parameters
kts	Knots
KIAS	Knots Indicated Airspeed
L	Left
LA	Look Angle
lbs	Pounds
M	Feedback Parameter
MIL	Military
MIN	Minute
MF	Feedback Parameter
MRT	Military Rated Thrust
N	Number of Segments
NAS	Naval Air Station
NATOPS	Naval Air Training & Operating Procedure Standardization Program
NAV	Navigation
NAVTRAEQUIPCEN	Naval Training Equipment Center
NF	Night Familiarization
NM	Nautical Miles

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS (cont.)

TERMS	
P	Parameter
P_e	Parameter Error
Pck	Control Score for parameter k
Pma	Procedures Score for maneuver a
Psn	Procedures Score for segment n
Psk	System Score for parameter k
PWR	Power Setting in % RPM
R	Right, Range
R&D	Research & Development
RI	Radio Instruments
rms	Root Mean Square
RPM	Revolutions Per Minute
R_T	Target Range
RTS	Readiness Training Squadron
sec	Second(s)
SESS	Session
SDV	Standard Deviation
S&L	Straight & Level
Sma	System Score for maneuver a
SRT	Standard Rate Turn
Ssn	System Score for segment n
S_A	Aileron Stick Input (angle)
S_E	Elevator Stick Input (angle)

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS (cont.)

TERMS	
SUB	Subsyllabus
t	Time
TAC	Tactical Air Command
TACAN	Tactical Air Navigation
TACF	Tactical Formation
TDFR	Target Displacement at Firing
TDLO	Target Development at Lock-On
Th	Throttle
TR	Technical Report
TRADEC	Training Device Computer
TURB	Turbulence
VF	Fighter Squadron
VT	Training Squadron
W	Weighting Factors
WEP	Weapons
WF	Weighting Factor
W_{ck}	Weight of Control Parameter score k
W_{nc}	Weight of Control Score for segment n
W_{ns}	Weight of System Score for segment n
W_{sk}	Weight of System Parameter score k
WST	Weapons System Training
XFM	Transform

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS (cont.)

SYMBOLS

α	Angle of Attack
β	Angle of Slide Slip
γ_T	Bearing to Target
Δ	Increment Change
Θ	Pitch
$\dot{\Theta}$	Pitch Rate
ϕ	Bank
$\dot{\phi}$	Roll Rate
ϕ_e	Bank Error
$\dot{\phi}_e$	Roll Rate Error
ψ	Heading
$\dot{\psi}$	Turn Rate
ψ_a	Interceptor Attack Heading
ψ_e	Heading Error
$\dot{\psi}_e$	Turn Rate Error
ψ_I	Initial Interceptor Heading
ψ_T	Target Heading
o	Degrees
'	Feet
G, g	Acceleration (Normal Acceleration)
h	Altitude
$\dot{h}$	Vertical Speed
h_e	Altitude Error
$\dot{h}_e$	Vertical Speed Error

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS (cont.)

SYMBOLS

h_i	Initial Interceptor Altitude
h_T	Target Altitude
R_T	Range to Target
t	Time
V	Speed
V_e	Speed Error
V_I	Initial Interceptor Speed
V_T	Target Speed

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